1993

EOS

reference handbook

earth

observing

system

(NASA-NP-202) 1993 EARTH OBSERVING SYSTEM REFERENCE HANDBOOK (NASA) 143 p
N93-23737
Unclas
H1/43 0157716

EOS

NASA

1993

EOS

reference handbook

earth

observing

system

EOS

NASA

Editors
Ghassem Asrar
David Jon Dokken

For additional copies:

Earth Science Support Office
Document Resource Facility
300 D Street, SW
Suite 840
Washington, DC 20024

202.479.0360 (voice)
202.479.2566 (FAX)

Acknowledgements

Special thanks must be extended to the Principal Investigators and Team Leaders for providing detailed information about their respective instruments, and to the Principal Investigators of the various Interdisciplinary Science Investigations for overviews of their study objectives. In addition, members of the EOS Project Engineering Office must be recognized for their assistance in verifying and enhancing the technical content of the document. Finally, thanks must be given to the international partners for providing up-to-date specifications of the instruments and platforms that help comprise the International Earth Observing System.

TABLE OF CONTENTS

Introduction 2
EOS Program Chronology 9
EOS Science Objectives 15
International Cooperation 21
Interagency Coordination 24
EOS Data and Information System (EOSDIS) 27
Pathfinder Data Sets 34
Data and Information Policy 36
Global Change Fellowship Program 38
Mission Elements 45
EOS Instruments 58
EOS Interdisciplinary Science Investigations 103
Points of Contact 134
Acronyms 142

List of Figures

1. Global Carbon Emissions and Mean Temperatures 3
2. USGCRP Global Change Science Priorities 7
3. Integrated Model of the Earth System 7
4. Restructured EOS Launch Profile (March 1992) 10
5. EOS Platform Instrument Counts and Data Rates 13
6. EOS Program Flight Elements (Post-Rescoping) 18
7. EOSDIS Architecture 28
8. EOSDIS Networking Strategy 29
9. Geographical Distribution of EOSDIS 30
10. U.S. and International Partner Earth-Observing Missions 44
11. EOS Rescoped Program-Level Architecture 46
12. The EOS-AM1 Satellite and Payload 47

List of Tables

1. MTPE Phase I: NASA Contributions 4
2. MTPE Phase I: Non-NASA Contributions 5
3. EOS Era Remote-Sensing Satellites 6
4. EOS Program History 9
5. Rescoped EOS Program 11
6. EOS Links to IPCC Areas of Scientific Uncertainty 17
7. The International Earth Observing System (1995-2002) 22
8. EOSDIS-Sponsored Data Centers 31
9. Pathfinder Data Availability 35
10. Global Change Fellowship Recipients—1990 to 1992 40

EARTH OBSERVING SYSTEM (EOS)

In the next century, planet Earth faces the potential hazard of rapid environmental change, including climate warming, rising sea level, deforestation, desertification, ozone depletion, acid rain, and reduction in biodiversity. Such changes would have a profound impact on all nations, yet many important scientific questions remain unanswered. For example, while most scientists agree that global warming is likely, its magnitude and timing (especially at the regional level) are quite uncertain. Additional information on the rate, causes, and effects of global change is essential to develop the understanding needed to cope with it. The National Aeronautics and Space Administration (NASA) is working with the national and international scientific communities to establish a sound scientific basis for addressing these issues through research efforts coordinated under the U.S. Global Change Research Program (USGCRP), the International Geosphere-Biosphere Program (IGBP), and the World Climate Research Program (WCRP).

THE NEED FOR THE MISSION

Scientific research shows that the Earth has changed over time, and continues to change. Human activity has altered the condition of the Earth by reconfiguring the landscape, by changing the composition of the global atmosphere, and by stressing the biosphere in countless ways. There are strong indications that natural change is being accelerated by human intervention. In its quest for improved quality of life, humanity has become a force for change on the planet, building upon, reshaping, and modifying nature—often in unintended ways.

Carbon dioxide, methane, nitrous oxide, and other gases trap heat emitted from the Earth's surface, thus warming the global atmosphere. Measurements over the past several decades have documented a rapid rise in concentrations of these greenhouse gases, but the long-term trend of global temperature is not yet predictable (see Figure 1). Changes in other variables (e.g., global cloudiness, concentration of atmospheric dust particles, ocean circulation patterns) also have an impact on global temperature. The existing space-based systems for global monitoring lack the spatial, temporal, and spectral coverage needed to provide observations of sufficient accuracy and precision to interpret the interactions among these variables, and their individual and combined contributions to global climate. Furthermore, current modeling of these interactive processes is not sufficiently accurate to generate reliable predictions of the magnitude and timing of global climate change.

Only through research can scientists further knowledge of climate change, providing guidance to policymakers who must balance the needs of constituents with the welfare of the planet and the species that inhabit it. The study of ozone levels by the Upper Atmosphere Research Program (UARP) illustrates how Earth science research yields a clear picture of human-induced global change. In the 1970s, scientists first proposed the chemical processes by which human-made chlorofluorocarbons (CFCs) deplete stratospheric ozone. After a long-term research program based on *in situ* and space-based observations, the international scientific community reached a consensus on global ozone depletion. The evidence and understanding gained from this research led to the Montreal Protocol for worldwide reduction in the production of CFCs in the 1990s.

MISSION OVERVIEW

Mission to Planet Earth (MTPE) is a NASA-initiated concept that uses space- and ground-based measurement systems to provide the scientific basis for understanding global change. NASA's contributions to MTPE include ongoing and near-term satellite missions, new missions under development, planned future missions, management and analysis of satellite and *in situ* data, and a continuing base research program focused on process studies and modeling. The space-based components of MTPE will provide a constellation of satellites to monitor the Earth from space. Sustained observations will allow researchers to monitor climate variables over time to determine trends; however, space-based monitoring alone is not sufficient. A comprehensive data and information system, a community of scientists performing research with the data acquired, and extensive ground campaigns are all important components. More than any other factor, the commitment to make Earth science data easily available to the research community proves critical to mission success. Brief descriptions of the various elements that comprise the overall mission are provided in the following subsections.

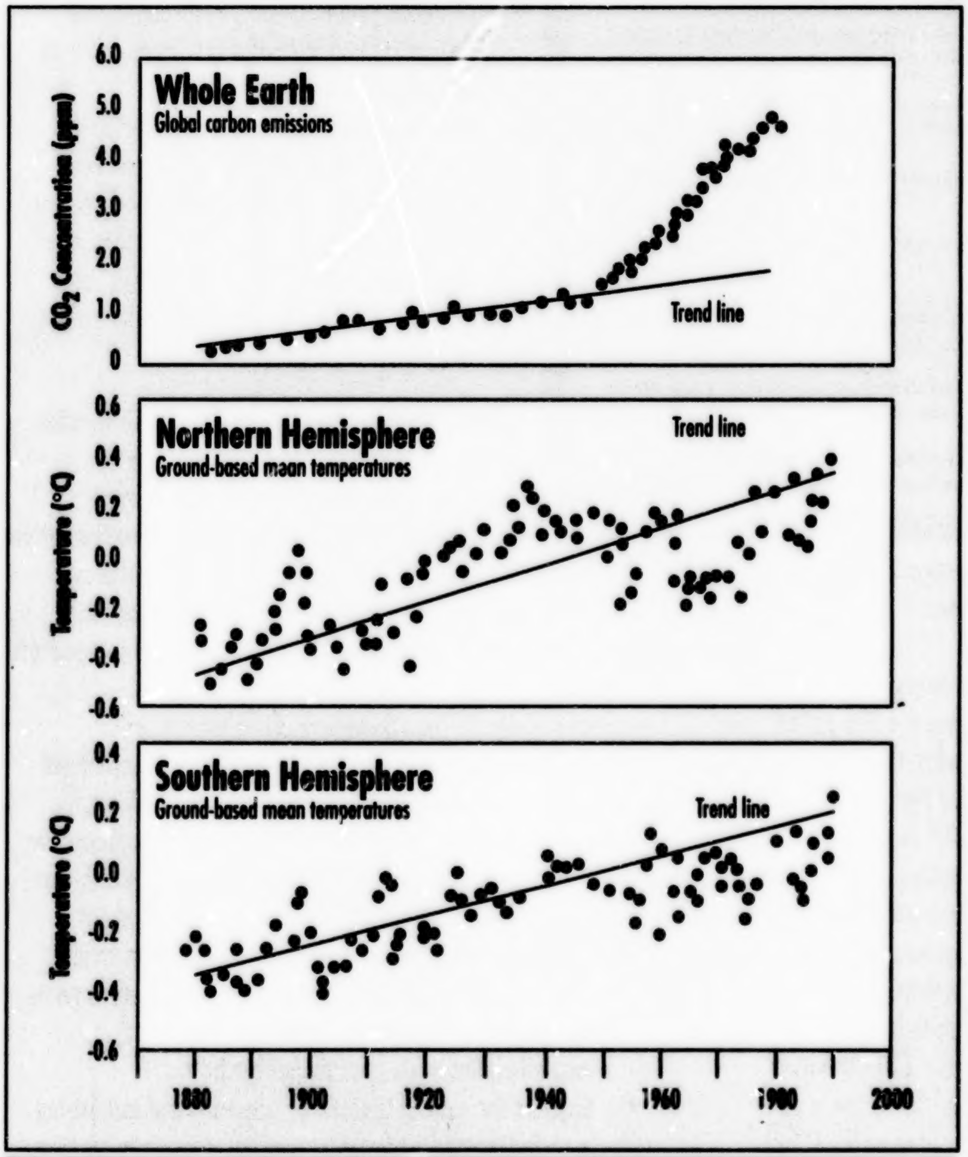


Figure 1. Global Carbon Emissions and Mean Temperatures

Mission to Planet Earth: Phase I

Satellites stationed in a variety of orbits form the space component of MTPE. No single orbit permits the gathering of complete information on Earth processes. For example, the medium-inclination orbit of the recently launched Upper Atmosphere Research Satellite (UARS) was chosen specifically because of the UARP focus on the processes influencing ozone depletion. High-inclination, polar-orbiting satellites are needed to observe phenomena that require relatively detailed observations on a routine basis, often from a constant solar illumination angle. Geostationary satellites are needed to provide continuous monitoring of high temporal resolution processes; an international array of these platforms now provides coverage on a near-global basis. This coverage will be improved early in the next century by geostationary satellites planned by NASA and its international partners. Each NASA flight program includes a dedicated science team, and the data from each will be made available to the global scientific community on a full and open basis.

Table 1 delineates NASA's contributions to Phase I of MTPE, and Table 2 identifies the international suite of Earth observations satellites that will be in place during this period.

Mission to Planet Earth: EOS Era

The Earth Observing System—a series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans—is the centerpiece of MTPE. In tandem with EOS, the polar-orbiting and mid-inclination platforms from Europe, Japan, and the U.S. National Oceanic and Atmospheric Administration (NOAA) form the basis for a comprehensive International Earth Observing System (IEOS). NASA, Japan, and the European Space Agency (ESA) programs will establish an international Earth-observing capability that will operate for at least 15

Table 1. MTPE Phase I: NASA Contributions

NASA Satellites (Launch Status)	Mission Objectives
ERBS (Operating) Earth Radiation Budget Satellite	Radiation budget, aerosol, and ozone data from 57° inclination orbit
TOMS/Meteor-3 (Operating) Total Ozone Mapping Spectrometer	Ozone mapping and monitoring (joint with Russia)
UARS (Operating) Upper Atmosphere Research Satellite	Stratospheric and mesospheric chemistry and related processes
NASA Spacelab Series (1992 on)	A series of Shuttle-based experiments to measure atmospheric and solar dynamics (ATLAS), atmospheric aerosols (LITE), and surface radar backscatter, polarization, and phase information [SIR-C and X-SAR (joint with Germany)]
TOPEX/Poseidon (Operating) Ocean Topography Experiment	Ocean circulation (joint with France)
LAGEOS-2 (Operating) Laser Geodynamics Satellite	Satellite laser-ranging target for monitoring crustal motions and Earth rotation variations (joint with Italy)
SeaWiFS (August 1993) Sea-Viewing Wide Field Sensor	Purchase of ocean color data to monitor ocean productivity
TOMS/Earth Probe (July 1994) Total Ozone Mapping Spectrometer	Ozone mapping and monitoring
NSCAT/ADEOS (February 1996) NASA Scatterometer	Ocean surface wind vectors (joint with Japan)
TOMS/ADEOS (February 1996) Total Ozone Mapping Spectrometer	Ozone mapping and monitoring (joint with Japan)
TRMM (August 1997) Tropical Rainfall Measuring Mission	Precipitation, clouds, and radiation processes in lower latitudes (joint with Japan)
Landsat-7 (December 1997) Land Remote-Sensing Satellite	High spatial resolution visible and infrared radiance/reflectance to monitor land surface (joint with DoD)

years. IEOS will allow scientists to obtain information at many levels of detail, covering all major Earth system processes.

Table 3 identifies the NASA, other U.S., and international contributions of Earth observations satellites during the EOS period. Additional details on these satellites are presented in the Mission Elements section of this Handbook. EOS will carry two classes of instruments: Facility Instruments supplied by NASA in response to general mission requirements, and Principal Investigator (PI) Instruments selected through a competitive process and aimed at the focused research interests of the selected investigators. Of course, the latter are also responsive to overall EOS objectives. The EOS Instruments section provides details on the science to be accomplished and engineering specifications for the 23 instruments remaining as part of the EOS Program (except for the as yet to be determined Japanese instrument to be accommodated on the EOS-CHEM series).

EOS science objectives address the fundamental physical, chemical, and biological phenomena that govern and integrate the Earth system. EOS observations will permit assessment of various Earth system processes, including the following:

- Hydrologic processes, which govern the interactions of land and ocean surfaces with the atmosphere through the transport of heat, mass, and momentum
- Biogeochemical processes, which contribute to the formation, dissipation, and transport of trace gases and aerosols, and their global distributions
- Climatological processes, which control the formation and dissipation of clouds and their interactions with solar radiation
- Ecological processes, which are affected by and/or will affect global change, and their response to such changes through adaptation
- Geophysical processes, which have shaped or continue to modify the surface of the Earth through tectonics, volcanism, and the melting of glaciers and sea ice.

The goal of the EOS mission is to advance scientific understanding of the entire Earth system by developing a deeper comprehension of the components of that system and the interactions among them. To quantify changes in the Earth system, EOS will provide systematic, continuous observations from low Earth orbit for a minimum of 15 years. Mission objectives in support of this goal are listed below:

- Create an integrated scientific observing system that will enable multidisciplinary study of the Earth's critical, life-enabling, interrelated processes involving the atmosphere, oceans, land surfaces, polar regions, and solid Earth, and the dynamic and energetic interactions among them
- Develop a comprehensive data and information system, including a data retrieval and processing system, to serve the needs of scientists performing an integrated, multidisciplinary study of planet Earth
- Support the overall USGCRP by acquiring and assembling a global database of remote-sensing measurements from space; priorities for acquiring these data will conform to

the seven issues identified by USGCRP and the Intergovernmental Panel on Climate Change (IPCC) as key to understanding global climate change (see Figure 2), including:

- The role of clouds, radiation, water vapor, and precipitation
- The productivity of the oceans, their circulation, and air-sea exchange
- The sources and sinks of greenhouse gases, and their atmospheric transformations
- Changes in land use, land cover, primary productivity, and the water cycle
- The role of polar ice sheets and sea level
- The coupling of ozone chemistry with climate and the biosphere
- The role of volcanoes in climate change.

To reach the above objectives, the EOS Program has pursued a number of initiatives beyond the development of EOS spacecraft and instruments. These essential elements—the EOS Data and Information System (EOSDIS), interdisciplinary research, education, and international coordination—receive coverage elsewhere in this Handbook.

The EOS Investigator Working Group (IWG)—which includes all selected Interdisciplinary Science Investigation PIs, Instrument PIs, Lead U.S. Co-Investigators for non-U.S. investigations, and Facility Instrument Team Leaders—establishes EOS science objectives in coordination with the national and international Earth science community. IWG and the following panels provide NASA with recommendations related to the design and implementation of all elements comprising EOS:

- Disciplinary Panels
  - Atmosphere
  - Biogeochemical Cycling
  - Land/Biosphere
  - Oceans
  - Solid Earth
- Interdisciplinary Panels
  - Modeling
  - Physical Climate and Hydrology
- Functional Panels
  - Calibration/Validation
  - EOSDIS Advisory
  - Instruments
  - Payload Advisory
  - Precision Orbit Determination/Mission Design.

Table 2. MTPE Phase I: Non-NASA Contributions

Non-NASA Satellites (Launch Status)	Mission Objectives
NOAA-9 through -J (U.S.—Operational)	Visible and infrared radiance/reflectance, infrared atmospheric sounding, and ozone measurements
Landsat-4/5/6 (U.S.—Operational) Land Remote-Sensing Satellite	High spatial resolution visible and infrared radiance/reflectance
DMSP (U.S.—Operational) Defense Meteorological Satellite Program	Visible, infrared, and passive microwave atmospheric and surface measurements
ERS-1 (ESA—Pre-Operational) European Remote-Sensing Satellite	C-band SAR, microwave altimeter, scatterometer, and sea surface temperature
JERS-1 (Japan—Pre-Operational) Japan's Earth Resources Satellite	L-band SAR backscatter and high spatial resolution visible and infrared radiance/reflectance
ERS-2 (ESA—1994) European Remote-Sensing Satellite	Same as ERS-1, plus ozone mapping and monitoring
Radarsat (Canada—1995) Radar Satellite	C-band SAR measurements of Earth's surface (joint U.S./Canadian mission)
NOAA-K through -N (U.S.—1994 on)	Visible, infrared, and microwave radiance/reflectance; infrared atmospheric sounding; and ozone measurements
ADEOS (Japan—February 1996) Advanced Earth Observing Satellite	Visible and near-infrared radiance/reflectance, scatterometry, and tropospheric and stratospheric chemistry (joint with U.S. and France)

The data collection segment of MTPE—EOS, Earth Probes, geostationary satellites, and ground-based programs—will provide the comprehensive global observations necessary to understand how the processes that govern global change interact as parts of the Earth system. Through this refined knowledge, models will be developed to help predict future environmental change on local, regional, and global scales. For those who make observations of the Earth system and develop models of its operation, Earth system science means the creation of interdisciplinary models that couple elements from formerly disparate sciences, such as ecology and meteorology. Figure 3 provides a conceptual model of the Earth system.

The EOS Program provides resources to support the scientific research required to turn satellite measurements into science data products for inclusion in or validation of models; specifically,

Table 3. EOS Era Remote-Sensing Satellites

Satellites (Launch Status)	Mission Objectives
EOS-AM Series (1998) Earth Observing System Morning Crossing	Clouds, aerosols and radiation balance, characterization of the terrestrial ecosystem; land use, soils, terrestrial energy/moisture, tropospheric chemical composition; contribution of volcanoes to climate, and ocean primary productivity (includes Canadian and Japanese instruments)
EOS-COLOR (1998) EOS Ocean Color Mission	Ocean primary productivity
POEM-ENVISAT Series (ESA—1998) Polar-Orbit Earth Observation Mission Environmental Satellite	Environmental studies in atmospheric chemistry and marine biology, and continuation of ERS mission objectives
ADEOS IIa and IIb (Japan—1999) Advanced Earth Observing Satellite IIa and IIb	Visible and near-infrared microwave radiance/reflectance, scatterometry, infrared and laser atmospheric sounding, tropospheric and stratospheric chemistry, and altimetry (may include French and U.S. instruments)
EOS-PM Series (2000) Earth Observing System Afternoon Crossing	Cloud formation, precipitation, and radiative properties; air-sea fluxes of energy and moisture; and sea-ice extent (includes European instruments)
EOS-AERO Series (2000) EOS Aerosol Mission	Distribution of aerosols and greenhouse gases in the lower stratosphere (spacecraft to be provided through international cooperation)
POEM-METOP Series (ESA—2000) Polar-Orbit Earth Observation Mission Meteorological Operational Satellite	Operational meteorology and climate monitoring, with the future objective of operational climatology (joint with EUMETSAT and NOAA)
TRMM-2 (Japan and NASA—Proposed for 2000) Tropical Rainfall Measuring Mission	Precipitation and related variables and Earth radiation budget in tropics and higher latitudes
EOS-ALT Series (2002) EOS Altimetry Mission	Ocean circulation and ice sheet mass balance (may include French instruments)
EOS-CHEM Series (2002) EOS Chemistry Mission	Atmospheric chemical composition; chemistry-climate interactions; air-sea exchange of chemicals and energy (to include an as yet to be determined Japanese instrument)

EOS supports scientific investigations through its Interdisciplinary Science Investigations and instrument teams:

- **EOS Interdisciplinary Science Investigations** are scientific studies selected through a competitive process to develop and refine integrated Earth system models, which will help in understanding the Earth as a system (see the EOS Interdisciplinary Science Investigations section for details on the 29 studies chosen as part of the EOS Program)
- **EOS Instrument Teams**, also selected through a competitive process, help define the scientific requirements for their respective instruments, and generate the algorithms that will be used to process the data into useful data products.

Refer to the EOSDIS Architecture section for a discussion of the different types of products to be made available as EOSDIS evolves to a full operational capability.

EOS investigations are intended to characterize the Earth system as an integrated whole, while also quantifying the regional processes that govern it. Research will be based initially on the existing sources of ground- and space-based observations (see Pathfinder Data Sets section), and will continue through and beyond the launch of the EOS satellites. Efforts to understand these Earth system elements will shed light on how the Earth functions as a coupled and integrated system, how it responds to human-induced perturbations, and how this response manifests itself as global climate change.

Mission to Planet Earth: Future Plans

NASA's long-range planning calls for continuation of MTPE into the next century. These plans include a new generation of satellites in geostationary orbit and additional Earth Probe satellites addressing specific Earth science investigations. Of course, the data system aspects of MTPE will continue throughout and beyond the lifetime of the EOS mission.

In addition to the approved Earth Probes missions identified in Table 1 (i.e., TOMS, NSCAT, and TRMM), several mission categories have been identified to provide critical Earth science measurements not provided by the international constellation of satellites. NASA intends to pursue collaborations with domestic and/or international partners in the following disciplines: Gravity and magnetic fields, solid Earth topography, and ocean topography. A follow-on to TOPEX/Poseidon is being actively sought to satisfy the latter category. Specific instrumentation and platforms have yet to be identified for the other two. Additional Earth Probes will be launched as particular observations are requested by the international science community, or as data gaps develop. The main driver behind this program is to provide focused missions in a faster, better, and cheaper manner, alleviating lengthy procurements. These small- to moderate-sized satellites will have extremely focused objectives, and obtain measurements that are not possible with EOS or other instrument suites.

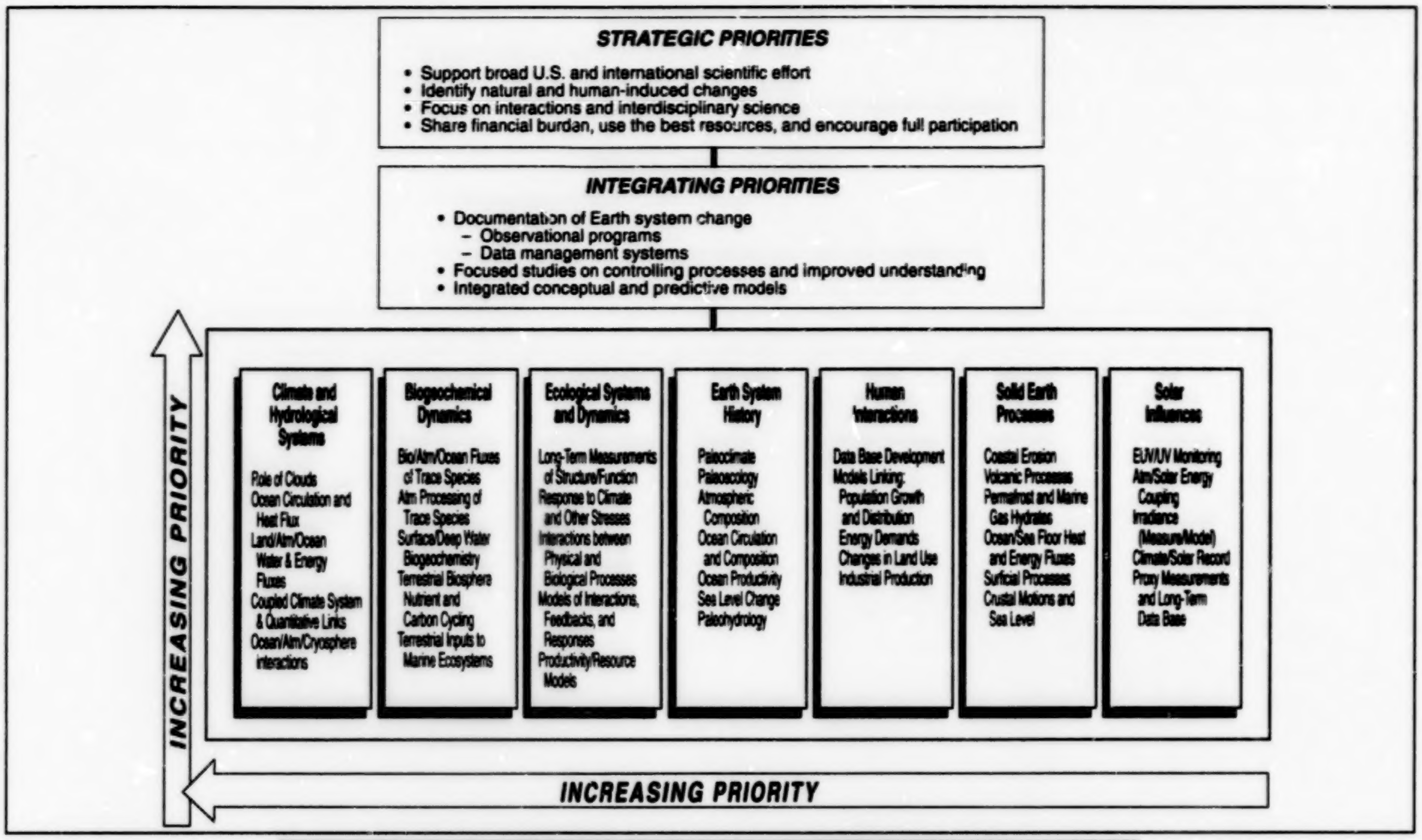

STRATEGIC PRIORITIES
• Support broad U.S. and international scientific effort
• Identify natural and human-induced changes
• Focus on interactions and interdisciplinary science
• Share financial burden, use the best resources, and encourage full participation
INTEGRATING PRIORITIES
• Documentation of Earth system change
– Observational programs
– Data management systems
• Focused studies on controlling processes and improved understanding
• Integrated conceptual and predictive models
INCREASING PRIORITY
Climate and Hydrological Systems
Role of Clouds
Ocean Circulation and Heat Flux
Land/Atm/Ocean Water & Energy Fluxes
Coupled Climate System & Quantitative Links
Ocean/Atm/Cryosphere interactions
Biogeochemical Dynamics
Bio/Atm/Ocean Fluxes of Trace Species
Atm Processing of Trace Species
Surface/Deep Water Biogeochemistry
Terrestrial Biosphere Nutrient and Carbon Cycling
Terrestrial Inputs to Marine Ecosystems
Ecological Systems and Dynamics
Long-Term Measurements of Structure/Function
Response to Climate and Other Stresses
Interactions between Physical and Biological Processes
Models of Interactions, Feedbacks, and Responses
Productivity/Resource Models
Earth System History
Paleoclimate
Paleoecology
Atmospheric Composition
Ocean Circulation and Composition
Ocean Productivity
Sea Level Change
Paleohydrology
Human Interactions
Data Base Development
Models Linking:
Population Growth and Distribution
Energy Demands
Changes in Land Use
Industrial Production
Solid Earth Processes
Coastal Erosion
Volcanic Processes
Permafrost and Marine Gas Hydrates
Ocean/Sea Floor Heat and Energy Fluxes
Surficial Processes
Crustal Motions and Sea Level
Solar Influences
EUV/UV Monitoring
Atm/Solar Energy Coupling
Irradiance (Measure/Model)
Climate/Solar Record
Proxy Measurements and Long-Term Data Base
INCREASING PRIORITY

Figure 2. USGCRP Global Change Science Priorities

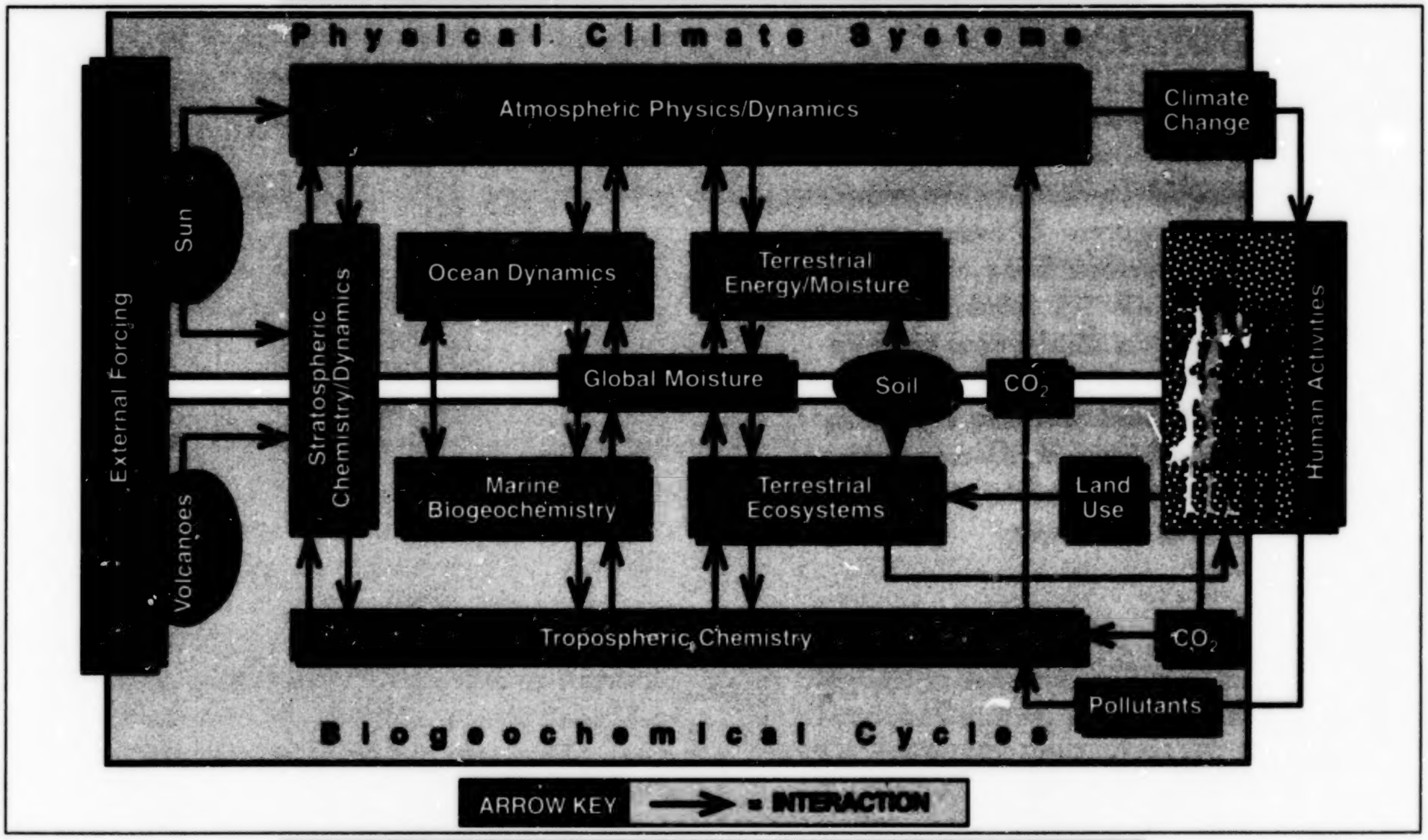

Physical Climate Systems
External Forcing
Sun
Volcanoes
Atmospheric Physics/Dynamics
Climate Change
Stratospheric Chemistry/Dynamics
Ocean Dynamics
Terrestrial Energy/Moisture
Global Moisture
Soil
CO_2
Human Activities
Marine Biogeochemistry
Terrestrial Ecosystems
Land Use
Tropospheric Chemistry
CO_2
Pollutants
Biogeochemical Cycles
ARROW KEY
= INTERACTION

Figure 3. Integrated Model of the Earth System

As currently envisioned, NASA's Geostationary Platform Program entails a constellation of five satellites making continuous observations concurrent with the polar-orbiting EOS satellites. The Geostationary Earth Observation (GEO) platforms are required to resolve dynamic processes that operate on the scale of minutes to hours, to detect unpredictable short-term events, and to observe weak signals that can only be detected by instruments capable of "staring" for relatively long periods. Much as geostationary weather satellites track storm systems today, these platforms will monitor dynamic short-term phenomena that cannot be observed from polar or low-inclination orbits. The science objectives for the geostationary platforms will complement those of the polar-orbiting and inclined orbit missions by improving understanding of short-term processes, which will then be incorporated into global Earth system models.

EOS and Earth Probes will provide high spatial resolution global information, and geostationary platforms will provide a time-continuous database over the full Earth disk. The various orbits of these space-based elements of MTPE will give Earth scientists as cohesive a set of observations—at all spatial and temporal scales—as possible on Earth system processes.

MISSION OUTLOOK

MTPE offers a new perspective on the functioning of planet Earth through coordinated, long-term, space-based and *in situ* observations, and a program of interdisciplinary research addressing priority issues of Earth system science. This Presidential Initiative is supported by Congress, which granted NASA a "new start" budget line item for the EOS Program in 1990. Following this mandate from the Administration and Congress, NASA has placed itself at the forefront of Earth observations satellite technology development and data management. The improved measurement and modeling capabilities that result directly support the U.S. and international global change research programs, and reinforce NASA's position as a world leader in space-based remote sensing.

The remainder of this Handbook describes the elements comprising the EOS mission in greater detail—its scientific foundations and the specific plans for bringing mission concepts to reality.

The EOS Program has undergone major revision since the last edition of this Handbook was published. The EOS Chronology section provides an overview of the reconfiguration of the program, which resulted from a Congressional mandate to substantially reduce the budget through 2000. The EOS Science section addresses the interdisciplinary focus on global climate change, a consequence of honing overall program objectives. A Pathfinder Data Set section has been added to inform readers of what is being done now to further global change research. Interagency cooperation in EOS has been strengthened through National Space Policy Directive 7, which established the Space-Based Global Change Observation System (S-GCOS). The Interagency Coordination/Cooperation section addresses this recent development. Finally, the reader should pay particular attention to the Mission Elements section, which provides details of the international instrument suites that comprise IEOS. This section provides as comprehensive and up-to-date coverage as possible given the transient nature of payload configurations imposed by constrained national budgets the world over. This section and the EOS Instruments section describe the current Earth remote-sensing satellite scenario and the instrumentation that will yield the observations needed to further global change research. ☆

EOS PROGRAM CHRONOLOGY

BACKGROUND

Planning for the EOS mission began in the early 1980s, and an Announcement of Opportunity (AO) for the selection of instruments and science teams was issued in 1988. 458 proposals were received in response to the AO. Early in 1990, NASA announced the selection of 30 instruments to be developed for EOS, along with their science teams; 29 Interdisciplinary Science Investigation teams were also selected at this time.

EOS was recognized as part of the Presidential initiative Mission to Planet Earth in 1990, receiving its "new start" from Congress in October. The EOS Program was funded under a continuing resolution, and ramped up to its full funding with the approval of the FY91 budget in January 1991. At that time, plans called for the instruments to be divided into three groups—the EOS-A and EOS-B series spacecraft, and for flight as attached payloads on Space Station *Freedom*. Instrument selections were also made for the proposed Japanese and European polar-orbiting satellites, then referred to as the Japanese Polar-Orbiting Platform (JPOP) and the European Polar-Orbiting Platform (EPOP). Table 4 provides the major milestones of the EOS Program to date.

Table 4. EOS Program History

Mission Planning	1982-87
Announcement of Opportunity	1988
Peer Review Process Letter Review (Academia/Government) Panel Review (Academia/Government) Prioritization Panel (Government)	1988-89
Announcement of Selection	1989
Definition Phase	1989-1990
New Start	1990
Execution Phase	1990 on
Restructuring Process	1991-92
Restructuring Confirmation	1992
Rescoping Process	1992
National Space Policy Directive 7	1992
Rescoping Confirmation	1993

THE NEED FOR RESTRUCTURING

In 1991, as directed by the U.S. Congressional Committee on Appropriations, the original plans for EOS were restructured for three principal reasons:

- Focus the science objectives of EOS on the most important problem of global change—global climate change
- Increase the resilience and flexibility of EOS by flying the instruments on multiple smaller platforms, rather than a series of large observatories
- Reduce the cost of EOS across the board (i.e., spacecraft, instruments, data system, and science), from $17 to 11 billion through FY2000.

To meet these constraints, NASA restructured the EOS Program via a thorough review by an external engineering committee, evaluation by the scientists who will use the EOS data, and systematic engineering studies of spacecraft configurations and launch options. The basic guiding principles for restructuring follow:

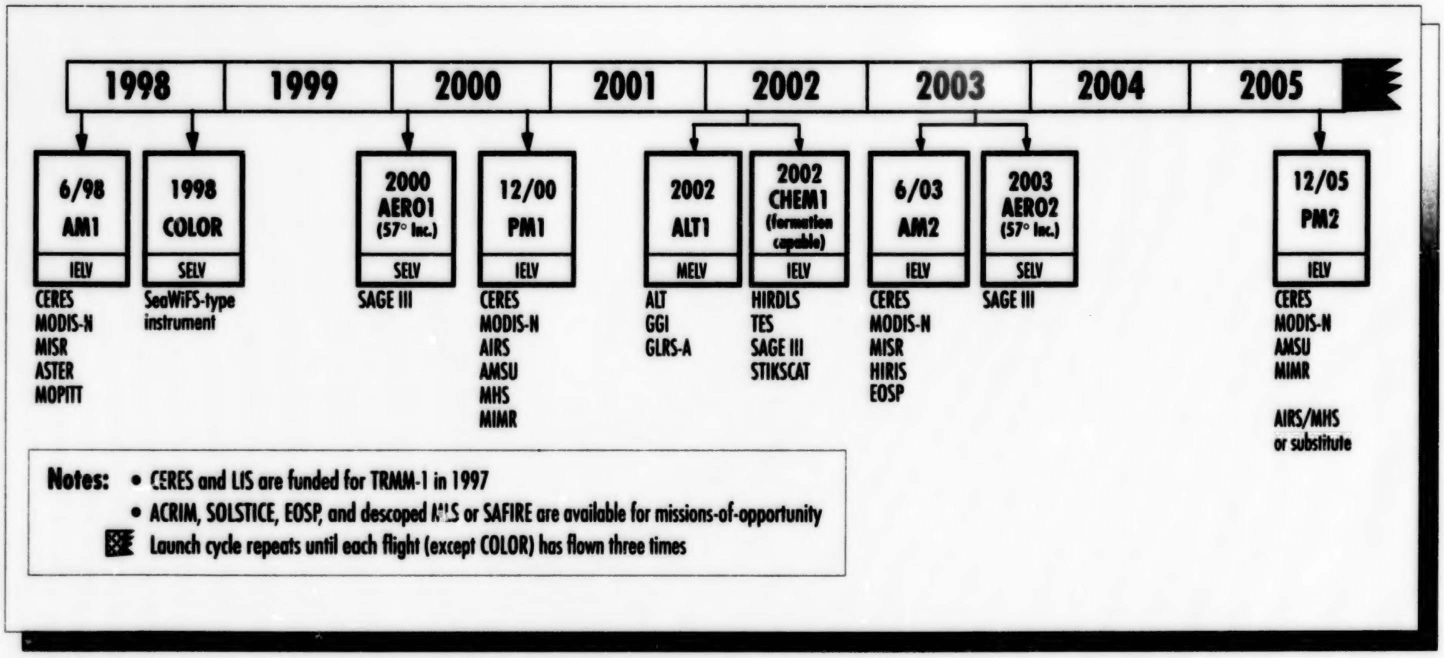
- Ensure continuity of observations for 15 years (though some instruments may be superseded or fly only once)
- Use the reports of IPCC, the Environmental Protection Agency (EPA), and the interagency Committee on Earth and Environmental Sciences (CEES) to prioritize policy-relevant science questions
- Identify a minimum complement of instruments to address each question
- Identify those instruments whose measurement objectives can be met by existing and/or potential instruments provided by others
- Deselect instruments where possible and as appropriate.

In July 1991, an EOS External Engineering Review (EER) Committee was convened in La Jolla, California. NASA and selected Interdisciplinary Science Investigation PIs briefed the EER Committee on the Congressional constraints, their opinions regarding reconfiguration, and options that they should consider. The EER Committee endorsed the presented options in its report as a "proof-of-concept" for an EOS that contains a "favorable measure of resiliency." In August 1991, NASA discussed payload options at the Seattle EOS IWG meeting; in October, a formal review was conducted by the EOS Payload Advisory Panel in Easton, Maryland. This latter body is composed of the EOS Interdisciplinary Science Investigation PIs, and is formally charged with examining and recommending EOS payloads to NASA based on the scientific requirements and priorities established by the Earth science community at large. Concurrently, extensive engineering studies were conducted at Goddard Space Flight Center (GSFC) to determine the most effective spacecraft configurations so that the instruments could be accommodated on smaller platforms. In December 1991, the NASA Administrator conducted a thorough review and approved the restructured EOS Program.

On March 9, 1992, NASA submitted a report on the restructuring of EOS to the Committees on Appropriations of the House of Representatives and Senate. Congress endorsed its contents as both comprehensive and fiscally responsible, with the final payload configurations for the restructured EOS satisfying all Congressional constraints. EOS focused on climate change; the observatories originally slated for launch aboard Titan IV expendable launch vehicles (ELVs) were to be launched on multiple smaller platforms via smaller ELVs; and the program was to have a total cost of $11 billion through FY2000. The final payloads were very similar to those endorsed by the EER Committee and wholly consistent with its recommendations. See Figure 4 for the payloads and launch dates of the restructured EOS. These payloads satisfied the recommendations of the EOS Payload Advisory Panel, with the caveat that some of the instruments would fly later than recommended due to budgetary constraints. Refer to the EOS Science Objectives section for the rationale leading to these payload configurations.

THE NEED FOR RESCOPING

The recommendations made by the EER Committee and the consequent restructuring of the EOS Program were based on an integrated 1992-2000 budget of $11 billion, down from the $17 billion projected in 1990. In October 1992, the FY93 appropriations bill passed by the U.S. Congress reduced the decadal budget to $8 billion; thus, in 2 years, the budget was essentially cut in half. Each cut has reduced the scope and resilience of the EOS Program. Obviously, lower funding requires that NASA pursue only the highest priority science and policy issues, significantly reducing the breadth of observations that were to be collected under the baseline plan of 1990.


1998
1999
2000
2001
2002
2003
2004
2005
6/98
AM1
IELV
CERES
MODIS-N
MISR
ASTER
MOPITT
1998
COLOR
SELV
SeaWiFS-type instrument
2000
AERO1
(57° Inc.)
SELV
SAGE III
12/00
PM1
IELV
CERES
MODIS-N
AIRS
AMSU
MHS
MIMR
2002
ALT1
MELV
ALT
GGI
GLRS-A
2002
CHEM1
(formation capable)
IELV
HIRDLS
TES
SAGE III
STIKSCAT
6/03
AM2
IELV
CERES
MODIS-N
MISR
HIRIS
EOSP
2003
AERO2
(57° Inc.)
SELV
SAGE III
12/05
PM2
IELV
CERES
MODIS-N
AMSU
MIMR
AIRS/MHS or substitute

Notes:
- CERES and LIS are funded for TRMM-1 in 1997
- ACRIM, SOLSTICE, EOSP, and descoped MLS or SAFIRE are available for missions-of-opportunity

▨ Launch cycle repeats until each flight (except COLOR) has flown three times

Figure 4. Restructured EOS Launch Profile (March 1992)

Rescoping studies had begun soon after the restructured EOS Program was endorsed by Congress. As part of an internal examination of all major programs, the NASA Administrator established "Red" and "Blue" Teams in May 1992, to review content, schedule, and cost. The Blue Team consisted of NASA employees (Headquarters and GSFC) who "own" the program and budget resources; the Red Team was composed of NASA employees [augmented by Jet Propulsion Laboratory (JPL) personnel] with project management experience outside of the program in question. The Red Team was charged with challenging the current approach and suggesting innovations to help NASA streamline its programs—that is, make them faster, better, and cheaper. The Administrator had also set a 30 percent reduction in budget as a target (i.e., from $11 to $8 billion), which was to act as a stimulus for the teams to reassess EOS content and configurations. Red and Blue Team recommendations focused on the budget for the later years, not the FY93 request which had already been pared back consistent with the above-mentioned Congressional directive. NASA Headquarters carefully considered the input of both the Red and Blue Teams and the EOS Payload Advisory Panel to arrive at the rescoped payloads listed in Table 5. As can be seen, most changes were confined to the EOS-ALT and -CHEM series payloads. Refer to the EOS Science Objectives section for more detail about instrument configurations and the impact that the rescoped program has on the science return.

EOS retains its emphasis on collecting observations over a 15-year period, but many important measurements have been cancelled or deferred due to the fact that it is now a "cost-driven" program. As can be seen in Table 5, several instrument changes are anticipated for the later launches in the EOS-AM and -PM series. Some instruments must now be provided by international partners, as will the spacecraft for the EOS-AERO series.

The descope to an $8 billion threshold required difficult tradeoffs to minimize the adverse impact on EOS science objectives. One key choice involved reducing the amount of contingency funds held to handle unexpected problems in

Table 5. Rescoped EOS Program

Launch	Spacecraft	Lifetime	Instrument Complement					
1998	AM1	5	MODIS	MISR	CERES (2)	MOPITT	ASTER	
2003	AM2	5	MODIS	MISR	CERES	EOSP	TES	MOPITT*
2008	AM3	5	MODIS	MISR	CERES	EOSP	TES	
1998	COLOR	3	SeaWiFS-Type					
2000	AERO1	3	SAGE III					
2003	AERO2	3	SAGE III					
2006	AERO3	3	SAGE III					
2009	AERO4	3	SAGE III					
2012	AERO5	3	SAGE III					
2000	PM1	5	MODIS	AMSU	MIMR	AIRS	MHS	CERES (2)
2005	PM2	5	MODIS	AMSU	MIMR	AIRS	MHS	CERES
2010	PM3	5	MODIS	AMSU	MIMR	AIRS	MHS	CERES
2002	ALT1	5	GLAS	TMR	SSALT	DORIS		
2007	ALT2	5	GLAS	TMR	SSALT	DORIS		
2012	ALT3	5	GLAS	TMR	SSALT	DORIS		
2002	CHEM1	5	HIRDLS	SOLSTICE II	ACRIM	MLS	SAGE III	TBD(J)
2007	CHEM2	5	HIRDLS	SOLSTICE II	ACRIM	MLS	SAGE III	TBD(J)
2012	CHEM3	5	HIRDLS	SOLSTICE II	ACRIM	MLS	SAGE III	TBD(J)

NOTES:

- AIRS, AMSU, HIRDLS, MHS, MIMR, and MODIS data available via direct broadcast
- ASTER data available via direct downlink
- CERES and LIS funded for TRMM-1 in 1997
- NSCAT II planned for flight on ADEOS II
- EOS-AERO spacecraft to be provided through international cooperation

*Accommodation of MOPITT on EOS-AM2 to be confirmed

TBD(J) = Japanese Instrument To Be Determined instrument development due to engineering and design challenges, and/or to accommodate changes in science requirements that drive specifications for the instruments and data system. This contingency had to be balanced against savings that would result from complete elimination of instruments and their associated scientific information. The Red and Blue Teams and the EOS Payload Advisory Panel recommended that NASA reduce program contingency funds in favor of a loss in future EOS design flexibility.

The Payload Advisory Panel, which represents the EOS investigators, believes that a properly structured $8 billion funding profile through the rest of this decade is enough to design and put in place the initial components of EOS. The increased risk associated with a reduction in contingency is implicitly mitigated, because EOS is a long-term measurement program with instruments flown on 5-year intervals. As such, instrument development problems or changes in science specifications could be handled in the next versions of the instruments. Obviously, some level of resilience and flexibility must be maintained to guarantee that a fully functional EOS be carried out regardless of ever-changing budgets, and to allow for the necessary technology developments that benefit U.S. competitiveness. Figure 5 shows the overlapping coverage that the phased launches will provide, and projects the total number of instruments in orbit at any given time over the first 12 years of the EOS Program.

The funding profile developed under the restructured program already reduced EOS to a minimum set of instruments to pursue the focused objective of global climate change. The measurement capabilities of the remaining instruments have been optimized to the maximum level possible, and further reductions prove unfeasible. At $8 billion, EOS must depend increasingly on the international partners. Failure to accomplish planned international cooperation on the Advanced Earth Observing System (ADEOS), Polar-Orbit Earth Observation Mission (POEM), Tropical Rainfall Measuring Mission (TRMM), and their follow-on missions will leave gaping holes in IEOS. Undoubtedly, further budget cuts would require wholesale elimination of instruments, thus information critical to understanding global climate change.

ENDORSEMENT BY THE NATIONAL SPACE COUNCIL

The National Space Council (NSpC), chaired by the Vice President, issued National Space Policy Directive 7 (NSPD 7) in June 1992, covering the space-based elements of USGCRP. This document directed NASA to implement the restructured EOS Program as part of an overall space-based global change observation system. Specifically, the policy directive formalized the following:

- **Establish a comprehensive, multiagency effort to collect, analyze, and archive space-based observations on global change**—The effort is led by NASA, with participation from other Government agencies.
- **Develop the EOS Program using small- and intermediate-sized satellites**—Through the use of advanced technology and reduced design complexity, these satellites can be acquired more quickly and at less cost than previously planned, allowing the timetable for obtaining critical data on global change to be accelerated.
- **Assign global change observation functions**—This category includes the development of technology, the collection of data, and the archival of data, to be accomplished through the combined efforts of NASA, the Department of Energy (DOE), the Department of Commerce (DOC), the Department of the Interior (DOI), and the Department of Defense (DoD).
- **Encourage international cooperation in global change observation from space**—This element directs the Department of State (DOS) to support the implementing agencies.

NSPD 7 established a focused national effort to improve multiagency collaboration in developing, collecting, analyzing, and archiving space-based observations of the Earth, with the ultimate goal of improving the world's ability to detect and document changes in global climate.

NSPD 7 directed NASA to coordinate production of an interagency program plan entitled "The Space-Based Global Change Observation System (S-GCOS) Program Plan: An Assessment of Current Status and Interagency Cooperation," which was first released in October 1992. In addition, NSPD 7 stipulated that the working group preparing this document identify an integrated plan for the development of new Earth remote-sensing instruments, missions, and associated technologies that involve NASA, DOE, and DoD. To meet their joint responsibilities, the participating agencies agreed on the following guidelines:

- Establish an interagency coordinating committee to guide the development and operation of S-GCOS

Figure 5. EOS Platform Instrument Counts and Data Rates

NOTES:

Platform Average Data Rates

EOS-AM1
18.525 Mbps

EOS-COLOR
0.665 Mbps

EOS-AM2/AM3
10.473 Mbps

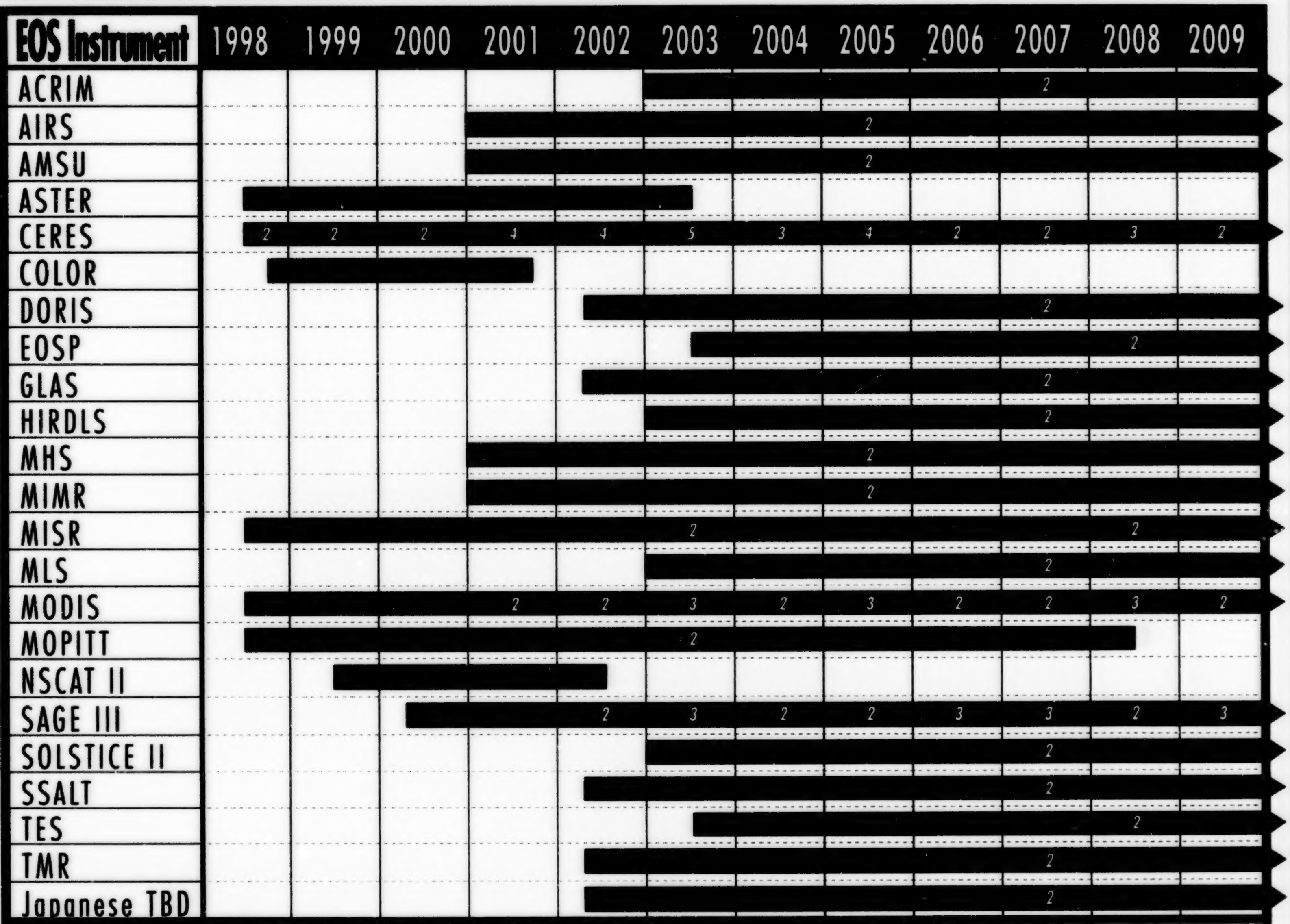
EOS-AERO Series
0.025 Mbps

EOS-PM Series
7.714 Mbps

EOS-ALT Series
0.280 Mbps

EOS-CHEM Series
0.997 Mbps

Numbers in timeline bars indicate copies in orbit once the instruments have commenced routine operations



EOS Instrument	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Avg. Data Rate	18.5	18.5	19.3	26.9	28.2	38.0	19.5	27.2	19.5	20.8	31.3	19.5
Instr. In Flight	6	7	9	16	21	31	24	30	24	33	28	23

- Coordinate interagency activities related to space-based global change observations, and provide an integrated S-GCOS annual report
- Participate with USGCRP in the development of the Global Change Data and Information System (GCDIS), of which EOSDIS is an integral element
- Assist in the review of USGCRP milestones related to space-based observations and data management
- Review agency programs and budgets related to space-based observations and data management
- Coordinate space-related activities with the appropriate oversight bodies
- Serve as liaison between S-GCOS and appropriate bodies of the National Academy of Sciences (NAS), and with other national and international bodies with interests in space-based global change observations and data management
- Manage the programs of their respective agencies so as to meet each agency's mission requirements, while providing planned support for S-GCOS activities.

In March of each year, the annual program plan will be submitted to CEES through the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) to NSpC, the National Security Council (NSC), the Office of Science and Technology Policy (OSTP), and the Office of Management and Budget (OMB). The annual report will address the S-GCOS architecture, existing and planned S-GCOS satellite systems, technology development activities, sensor suites, launch systems, supporting agency contributions, and data and information systems. Specifically, the plan will identify innovative flight alternatives (e.g., small satellites, or piggybacks on commercial or military launches) and sensor options that might provide the earliest possible availability of high-priority observations or that fill critical gaps in the existing observation plan.

At present, the S-GCOS Program Plan Working Group has identified three primary Earth remote-sensing areas where joint-use requirements and/or associated research and technology development prove suitable for collaboration between NASA, DOE, and DoD: Laser remote sensing of atmospheric winds, high-resolution multispectral imaging of the Earth's surface, and synthetic aperture radar (SAR) imaging of the Earth's surface. In December 1992, working groups were established to review coordination among agency programs and schedules, science matters, data management matters, and technology improvement needs—all of which will be addressed in the first S-GCOS Annual Report slated for release in March 1993.

As can be seen in the above discussion, the EOS Program has helped decisionmakers recognize the value of space-based global climate observations. Over the past decade, politicians—both at the national and international level—have become increasingly more aware of the urgency of collecting such information on a global scale. NASA and its interagency/international partners have undertaken an exciting challenge to provide the necessary data and knowledge required to establish sound policy decisions on human activities, which have a direct effect on the global environment. Informed and timely decisions are needed to guide the stewardship of planet Earth and ensure its habitability for future generations. ☆

EOS SCIENCE OBJECTIVES

The primary goal of the rescoped EOS Program remains that of the restructured EOS—that is, to determine the extent, causes, and regional consequences of global climate change. The extent (e.g., the change in average temperature and the time scale over which it will occur) is presently unknown. Causes can be either natural or human-induced. Both must be understood to determine how to alter human behavior and avoid climate changes that prove most detrimental to the environment. The regional consequences (e.g., changes in precipitation patterns, length of growing seasons, severity of storms, sea level) must be understood to determine which aspects of climate change are most harmful, and how to adapt to those changes that the human species cannot avoid.

EOS IWG defined the following science and policy priorities for EOS observations, based on IPCC, EPA, and CEES recommendations:

1) Water and Energy Cycles
   - Cloud formation, dissipation, and radiative properties, which influence response of the atmosphere to greenhouse forcing
   - Large-scale hydrology and moisture processes, including precipitation and evaporation
2) Oceans
   - Exchange of energy, water, and chemicals between the ocean and atmosphere, and between the upper layers of the ocean and deep ocean (includes sea ice and formation of bottom water)
3) Chemistry of Troposphere and Lower Stratosphere
   - Links to the hydrologic cycle and ecosystems, transformations of greenhouse gases in the atmosphere, and interactions inducing climate change
4) Land Surface Hydrology and Ecosystem Processes
   - Improved estimates of runoff over the land surface and into the oceans
   - Sources and sinks of greenhouse gases
   - Exchange of moisture and energy between the land surface and atmosphere
   - Changes in land cover
5) Glaciers and Polar Ice Sheets
   - Predictions of sea level and global water balance
6) Chemistry of the Middle and Upper Stratosphere
   - Chemical reactions, solar-atmosphere relations, and sources and sinks of radiatively important gases
7) Solid Earth
   - Volcanoes and their role in climatic change.

RESTRUCTURED EOS PROGRAM

The instruments flying as part of the restructured EOS Program were chosen to address these key scientific issues associated with global climate change. The original EOS Program covered a broader range of global change issues, including studies of stratospheric chemistry and its controlling influence on ozone depletion, and aspects of solid Earth physics and the exosphere. The baseline EOS Program included a total of 30 selected instruments. By focusing on climate change, the required instruments were reduced to 17 that needed to fly before 2002. Six were deferred, and seven were deselected during the restructuring process.

With input from the EER Committee and detailed recommendations from the EOS Payload and Science Advisory Panels, NASA reconfigured EOS to fly the 17 instruments required for global climate change studies, as follows: 1) Three intermediate spacecraft series to be launched on IELVs, 2) one smaller spacecraft series to be launched on MELVs, and 3) two small spacecraft series to be launched on SELVs. The names of the spacecraft series, initial launch date, launch vehicle class, and disciplinary focus follow:

- **EOS-AM** (June 1998, IELV)—Characterization of the terrestrial and oceanic surfaces; clouds, radiation, and aerosols; and radiative balance
- **EOS-COLOR** (1998, SELV)—Ocean color and productivity
- **EOS-AERO** (2000, SELV)—Atmospheric aerosols and ozone
- **EOS-PM** (2000, IELV)—Clouds, precipitation, and radiative balance; terrestrial snow and sea ice; sea-surface temperature; terrestrial and oceanic productivity; and atmospheric temperature

- **EOS-ALT** (2002, MELV)—Ocean circulation, ice sheet mass balance, and land-surface topography
- **EOS-CHEM** (2002, IELV)—Atmospheric chemical species and their transformations, and ocean surface stress.

The launch of the first EOS-AM spacecraft was rescheduled to June 1998, 6 months earlier than the originally planned launch of the first large EOS observatory (i.e., EOS-A). By reducing the size of the spacecraft and its payload, it became possible to launch earlier. The launch dates of the remaining EOS spacecraft were scheduled to occur over the ensuing 4 years, through the year 2002. Refer back to Figure 4 for a timeline and listing of instruments making up the restructured EOS Program.

The restructured program had the EOS-AM and -PM satellite series both employing sun-synchronous polar orbits, but with different crossing times. The EOS-AM spacecraft primarily would observe terrestrial surface features; thus, a morning crossing time (when cloud cover is at a minimum over land) proved preferable. In contrast, EOS-PM included a next-generation atmospheric sounder—a candidate for deployment on future NOAA operational satellites. The instruments on this platform were suitable for an afternoon crossing time. Both EOS-AM and -PM would observe characteristics of terrestrial and oceanic surfaces, and the atmosphere. By having measurements at two different times of day, it would be possible to study diurnal variations in these features. EOS-COLOR, -ALT, and -CHEM were also slated for sun-synchronous polar orbits, and EOS-AERO was to have a 57° inclination.

Certain instruments were to be flown on more than one spacecraft. The Moderate-Resolution Imaging Spectroradiometer (MODIS), which is capable of observing both the Earth's surface and atmosphere, was included on both EOS-AM and -PM because of its synergy with other instruments on these platforms. That is, MODIS observations obtained simultaneously through the same atmospheric column are important in interpreting data from the other instruments. By flying on two separate spacecraft, MODIS—now the central instrument of EOS—would provide important redundancy to the program. MODIS would yield cloud information to complement the radiation budget observations taken by the Clouds and Earth's Radiant Energy System (CERES) instrument, which also was scheduled to fly on both the EOS-AM and -PM satellites as well as TRMM. Two MODIS instruments would provide complete global ocean color measurements by avoiding sun glint over the northern hemisphere oceans and the lack of illumination over the southern oceans, to be accomplished through their complementary ascending and descending orbits. The continuity of ocean color data beyond 2000 would be assured by including MODIS on both platforms. By flying on TRMM and both EOS-AM and -PM, CERES would provide Earth radiation budget from three different orbits at different times of the day, thus capturing diurnal changes.

The Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument, which measures atmospheric aerosols, would be flown on EOS-AERO and -CHEM to provide measurements from two different orbits (57° inclination and polar, respectively). This strategy would also guarantee complete global coverage.

As stated earlier, the science objectives resulting from the restructuring exercise narrowed the overall study of global change down to an examination of global climate change. The extent, causes, and regional consequences of global climate change were to be determined by 1) providing a continuous calibrated data set of key Earth science variables in order to monitor variability and detect trends; 2) observations that will lead to an enhanced understanding of processes in order to improve predictive models; and 3) an information system for the receipt, processing, archiving, and dissemination of data to the scientific community and policymakers. The latter two remained virtually intact from the baseline EOS Program approach; rather, the observations to be collected and the instruments that were to take the measurements came under scrutiny. The selected EOS instruments and spacecraft ensured continuity of important time series of climate measurements, addressed the high-priority science and policy issues identified by IPCC, and were consistent with technical, budgetary, and schedule constraints.

The program plans that came out of the restructuring exercise were tempered by the caveat that follow-on EOS spacecraft payload configurations could change, depending on the evolution of scientific understanding and/or technological developments. For example, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on the first EOS-AM platform possibly was going to be replaced by the High-Resolution Imaging Spectrometer (HIRIS) on EOS-AM2. The Payload Advisory Panel stipulated that actual decisions on instruments to fly on follow-on spacecraft did not need to be made immediately; rather, their rationale was to continue technology development efforts to ensure that subsequent generation instruments were available when needed. This proved a wise approach, given that the the restructuring recommendations were approved by Congress in March 1992, and the Red and Blue Team reviews were initiated by the NASA Administrator a mere 2 months later.

RESCOPED EOS PROGRAM

The rescoped EOS Program retains the focus on global climate change instituted in the restructuring exercise. The EOS Program still emphasizes data collection over a 15-year period; however, many important measurements were cancelled or deferred due to the high-risk technologies involved and associated cost. The descope of EOS to an $8 billion threshold required difficult tradeoffs to maximize science. As stated in the EOS Chronology section, the amount of contingency funds held to handle unexpected problems had to be reduced substantially. This contingency had to be balanced against the savings that resulted from complete elimination of instruments and their associated scientific information. This section identifies the principal factors considered by the Payload Advisory Panel and the Red and Blue Teams in the rescoping effort. Resolution is expected in 1993. A brief synopsis of key rescoping developments follows:

- All commitments to fly international instruments and the June 1998 launch date of EOS-AM have been maintained.
- To the extent possible, the science requirements identified by the EOS restructuring have been preserved.
- The reduction in the EOS budget has increased reliance on interagency and international cooperation.
- Common spacecraft will be developed for EOS-PM, -CHEM, and -AM2/-AM3 (EOS-AERO and -ALT remain unique).
- The HIRIS instrument has been eliminated, although funding for the science team will be maintained through 1994 to help address key scientific questions and clearly define observational requirements.

Table 6 lists areas of scientific uncertainty identified by IPCC and the rescoped EOS Program instruments that will address each issue. EOS remains a long-term program, providing continuous observations of the causes of global climate change; therefore, each EOS spacecraft will be repeated twice on 5-year centers to provide at least 15-year coverage. The only exceptions involve EOS-AERO (four follow-on launches on 3-year centers) and the one-time EOS-COLOR mission because of the lifetime limitations associated with small ELVs. The development of EOSDIS, its support of precursor data sets, and provision of a reduced set of essential data products at the launch of each EOS element has been maintained.

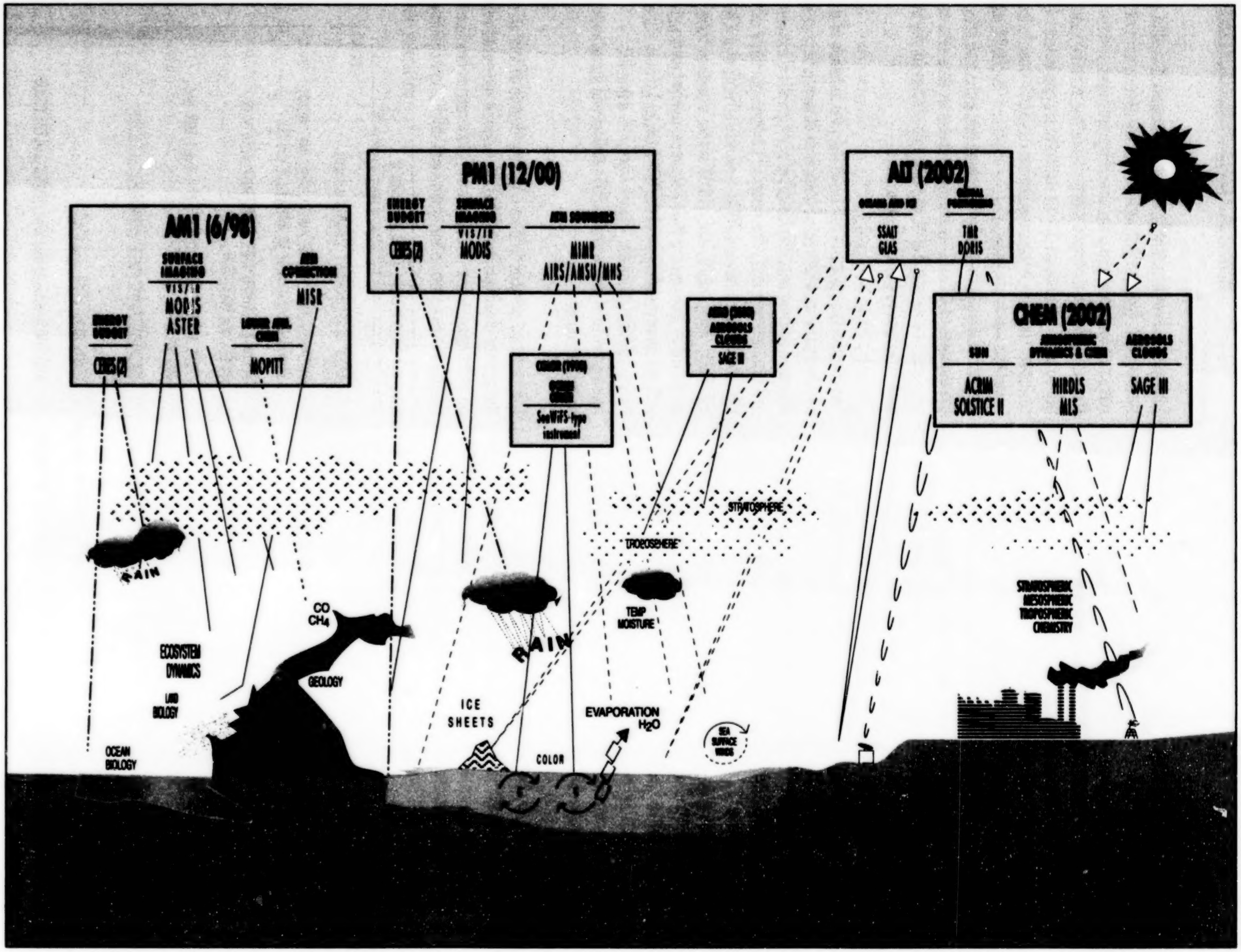
The principal reductions in cost result from the initiation of a common bus development, a decreased number of at-launch data products, increased international and interagency cooperation, increased risk, and rescoped payloads. The rescoped payloads primarily affect those platforms planned beyond 2000—namely EOS-ALT and -CHEM. The EOS-AM1, -PM1, -AERO, and -COLOR science objectives have been preserved by maintaining their instrument complements consistent with the recommendations of the EOS Payload Advisory Panel and the restructured program. Figure 6 provides a graphic representation of the rescoped EOS satellites and the science objectives sought.

The rescoped program places a greater degree of risk on meeting the science objectives beyond 2000, because increased reliance on other agency and international collaborations has been assumed where firm commitments are still being negotiated. In particular, the

Table 6. EOS Links to IPCC Areas of Scientific Uncertainty

IPCC Category	EOS Instrument Complement
Sources and sinks of greenhouse gases, which affect predictions of their future concentrations	AIRS/AMSU/MHS, ASTER, HIRDLS, MIMR, MLS, MODIS, MOPITT, NSCAT II, SAGE III, SOLSTICE II, and TES
Clouds and radiative balance, which strongly influence the magnitude of climate change at global and regional scales	ACRIM, AIRS/AMSU/MHS, CERES, EOSP, MIMR, MISR, MODIS, and SOLSTICE II
Oceans, which influence the timing and patterns of climate change	CERES, MIMR, MISR, MODIS, NSCAT II, SSALT, TMR, and EOS-COLOR
Land surface hydrology, which affects regional climate change and water availability	AIRS/AMSU/MHS, ASTER, MIMR, MISR, and MODIS
Polar ice sheets, which affect predictions of global sea level changes	DORIS, GLAS, MIMR, and SSALT
Ecological dynamics, which are affected by and respond to climate change	AIRS/AMSU/MHS, ASTER, MISR, MODIS, and EOS-COLOR

Figure 6. EOS Program Flight Elements (Post-Rescoping)


AM1 (6/98)
ENERGY BUDGET
CERES (2)
SURFACE IMAGING
VIS/IR
MODIS
ASTER
LOWER ATM. CHEM
MOPITT
ATM CORRECTION
MISR
PM1 (12/00)
ENERGY BUDGET
CERES (2)
SURFACE IMAGING
VIS/IR
MODIS
ATM SOUNDERS
MIMR
AIRS/AMSU/MHS
COLOR (1998)
OCEAN COLOR
SeaWiFS-type instrument
AERO (2000)
AEROSOLS CLOUDS
SAGE III
ALT (2002)
OCEANS AND ICE
SSALT
GLAS
GLOBAL POSITIONING
TMR
DORIS
CHEM (2002)
SUN
ACRIM
SOLSTICE II
ATMOSPHERIC DYNAMICS & CHEM
HIRDLS
MLS
AEROSOLS CLOUDS
SAGE III
STRATOSPHERE
TROPOSPHERE
RAIN
RAIN
CO
CH4
ECOSYSTEM DYNAMICS
LAND BIOLOGY
GEOLOGY
OCEAN BIOLOGY
ICE SHEETS
COLOR
EVAPORATION H2O
TEMP MOISTURE
SEA SURFACE WINDS
STRATOSPHERIC MESOSPHERIC TROPOSPHERIC CHEMISTRY

deletion of HIRIS was predicated on the joint DoD/NASA partnership in Landsat. This action has been resolved since initiation of the Red and Blue Team reviews, with management responsibility to be completely transferred from NOAA to the integrated DoD/NASA team with the launch of Landsat-7.

Developing a common spacecraft bus preserves the science objectives by increasing payload flexibility, by simplifying instrument design through a known interface, and by allowing for a launch opportunity every 18 to 30 months. This approach will only be realized if minimal redesign is required for each spacecraft and instrument grouping. The chief concern of the Red and Blue Teams and EOS Payload Advisory Panel was to determine optimum characteristics that best support the groupings identified in Table 5. This resulted in EOS-AM1 having a unique design, with -PM1 the first common bus to be used on all subsequent spacecraft (except EOS-AERO, -COLOR, and -ALT). IELVs remain the launch vehicles of choice, because this class best accommodates the payload needs developed during the restructuring and rescoping deliberations. The EOS-ALT and -AERO series can be accommodated on smaller ELVs.

Continuing the current EOS-AM1 development effort provides the greatest assurance of meeting the June 1998 launch readiness date. The EOS Program no longer requires EOS-AM2 to have the same performance characteristics as -AM1. This development effort should not be considered for naught, because this spacecraft could serve as the basis for future Landsat-class missions. This spacecraft will be able to handle multiple high-resolution instruments, which require more power, pointing, and data-handling capabilities than other EOS missions.

The payloads after 2000 were shifted primarily to take advantage of ongoing discussions between NASA and the international community. This may allow scatterometer measurements to be advanced by approximately 2 years, if sufficient resources are made available to accommodate the NASA Scatterometer follow-on (NSCAT II) on Japan's ADEOS II. This provides greater assurance of the continuity of ocean wind stress and topography measurements needed to study ocean circulation and air-sea exchange of energy and chemicals. The NSCAT accommodation on the original EOS-CHEM1 payload was considered a flight-of-opportunity in order to continue the observations begun with ADEOS I, which is scheduled for launch in 1996. Such a scenario would have required that NSCAT operate for at least 6 years prior to the launch of the EOS-CHEM1 mission. The rescoped scenario assumes flight of NSCAT II in 1999, significantly reducing risk of a gap in scatterometry data.

Two French instruments presently onboard the TOPEX/Poseidon mission [i.e., Solid-State Altimeter (SSALT) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)] will provide needed altimetric observations by replacing the U.S. Altimeter (ALT) and GPS Geoscience Instrument (GGI), respectively. However, the science return will be reduced. SSALT currently does not operate in two frequencies (required for the correction of ionospheric effects), and the substitution of DORIS provides precise tracking but eliminates the sparse, accurate, atmospheric temperature profiles that GGI would generate. Both the Red and Blue Teams and Payload Advisory Panel took these factors into consideration when weighing science return against the costs involved.

The continuation of the Landsat Program allowed the placement of the Tropospheric Emission Spectrometer (TES)—instead of HIRIS—on EOS-AM2, together with MODIS and possibly the Measurements of Pollution in the Troposphere (MOPITT) instrument. This reconfiguration also allowed the inclusion of several flight-of-opportunity instruments [i.e., Active Cavity Radiometer Irradiance Monitor (ACRIM), Solar Stellar Irradiance Comparison Experiment II (SOLSTICE II), and Microwave Limb Sounder (MLS)] on the EOS-CHEM series. These instruments will generate measurements of atmospheric chemical composition, radiation, and dynamics complementary to observations currently being collected by the MLS and SOLSTICE II instruments aboard UARS.

As in the restructured EOS scenario, SAGE III measurements will be provided by both EOS-AERO and -CHEM satellites, which will fly in 57° inclined and polar orbits, respectively. By placing this instrument in different orbits, full global coverage can be guaranteed. The spacecraft for the EOS-AERO mission has yet to be determined; however, NASA negotiations for an international partnership in the aerosols series should be completed in 1993.

Through the rescoping exercise, the EOS Program has decreased instrument contingency funds to be more representative of a multiple copy procurement, and has phased instrument developments to control initial costs and bring the overall budget within the Congressionally mandated ceiling. As a result, the total number of instruments to fly on the EOS platforms (including international contributions) has been reduced to 22, of which 15 will fly before 2003. ASTER is slated for only one flight, and negotiations are still underway to accommodate MOPITT on the second EOS-AM platform; a slot for an as yet to be determined Japanese instrument for flight on the EOS-CHEM series has been held as reciprocation for the flight of NSCAT II on the ADEOS series. Of course, instrument complements could change with the evolution of scientific understanding and/or technological enhancements. Refer to the EOS Instruments section for descriptions of those instruments that remain part of the EOS Program.

The reconfiguration of the EOS payloads has both benefits and pitfalls; yet, in the prevailing budget environment, decisionmakers have to balance the science return against costs incurred. Any rearrangements require review by EOS IWG to determine if they represent an acceptable solution towards satisfying the identified IPCC science and policy priorities. Furthermore, the potential of achieving the international commitments assumed in the rescoped program must be quantified to determine the consequences of data gaps should these collaborations not be realized. ☆

INTERNATIONAL COOPERATION

The Earth Observations International Coordination Working Group (EO-ICWG) is the forum within which the U.S., Europe, Japan, and Canada discuss, plan, and negotiate the international cooperation essential for implementation of the International Earth Observing System in the 1990s and beyond. The delegations to EO-ICWG are led by the Earth observations offices of their respective space agencies: The National Aeronautics and Space Administration (NASA); the European Space Agency (ESA); the Science and Technology Agency (STA), the National Space Development Agency (NASDA), and the Ministry of International Trade and Industry (MITI); and the Canadian Space Agency (CSA). The delegations also include respective operational environmental monitoring agencies: The National Oceanic and Atmospheric Administration (NOAA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the Japan Meteorological Agency (JMA), and the Atmospheric Environment Service (AES). The group meets two to three times per year, addressing a full range of technical and policy issues, which include payload, operations, data management, data policy, and instrument interfaces. EO-ICWG has defined the elements listed below as the space-based component of IEOS:

- NASA's Earth Observing System (EOS) missions
- Japan's Advanced Earth Observing System (ADEOS) missions
- NASA/NASDA Tropical Rainfall Measuring Mission (TRMM) and follow-ons
- ESA's Polar-Orbit Earth Observation Mission (POEM) satellites
- NOAA's Polar-Orbiting Operational Environmental Satellite (POES) series.

Table 7 lists the IEOS satellites and their respective instrument complements. Given the transience of national budget scenarios (consequently scheduling), this chart should be considered a planning document. Refer to the Mission Elements section for more detail on the various spacecraft that comprise IEOS. The paragraphs below offer brief synopses of the partner nation contributions.

EUROPE

Originally a single polar-orbiting platform series concept, ESA's POEM mission recently was split into two satellite series—one for environmental monitoring and atmospheric chemistry (ENVISAT), and one for operational meteorological and climate monitoring (METOP). The spacecraft, instrumentation, launch, operations, and associated data system are provided through ESA, individual member state contributions, and EUMETSAT. ESA's plans call for the first flight of POEM-ENVISAT in mid-1998, with a follow-on flight in 2003. This satellite series will contribute to environmental studies in land surface properties, atmospheric chemistry, aerosol distribution, and marine biology. The second satellite series—POEM-METOP—will fly an operational meteorological package and climate monitoring instrumentation in cooperation with EUMETSAT and NOAA. This series will take over morning operational satellite coverage from the NOAA POES system in 2000.

As a result of the rescoping exercise, France may contribute two TOPEX/Poseidon-heritage instruments for flight on the EOS-ALT series (i.e., DORIS and SSALT). An international science team will be formed to conduct global climate change research using data from these instruments.

Further European contributions to IEOS include provision of the Multifrequency Imaging Microwave Radiometer (MIMR) by ESA for flight on the EOS-PM series; the Microwave Humidity Sounder (MHS) by EUMETSAT for flight on the EOS-PM series; and the High-Resolution Dynamics Limb Sounder (HIRDLS)—a joint U.S./U.K. instrument investigation—for flight on the EOS-CHEM series. European scientists participate in these and other instrument investigation teams. Finally, France and the U.K. are sponsoring several EOS Interdisciplinary Science Investigations (see pages 115, 122, and 129).

JAPAN

ADEOS, TRMM, and their follow-ons are the Earth observation missions designated as the Japanese contributions to IEOS. In tandem with their predecessors [e.g., Japan's Earth Resources Satellite-1 (JERS-1)], these satellites constitute the Japanese Earth Observing System (JEOS). Japan plans to launch the polar-orbiting ADEOS mission in February 1996, into a sun-synchronous 98.6° inclination orbit, with an ~800-km altitude. The objectives of ADEOS include Earth, atmospheric, and oceanographic remote sensing.

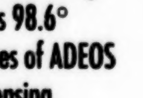


Table 7. The International Earth Observing System (1995-2002)

	PROPOSED INSTRUMENT CONFIGURATION													
	ADEOS 799.8 km 10:30 a.m. 1Q 1996	*NOAA-K 1:30 p.m. Polar 2Q 1996*	*NOAA-L 7:30 a.m. Polar 2Q 1997*	*TRMM-1 350 km 35° Inclination 3Q 1997*	*EOS-AM1 705 km 10:30 am 2Q 1998*	*EOS-COLOR Polar 1998*	*ADEOS II Polar 1999*	*POEM-ENVISAT1 1998*	*NOAA-M/N/N' PM/PM/PM Polar 1999, 2000, 2002*	*EOS-AERO1 57° Inclination 2Q 2000*	*EOS-PM1 705 km 1:30 pm 4Q 2000*	*POEM-METOP1 2000*	*EOS-ALT1 Polar 1Q 2002*	*EOS-CHEM1 Polar 3Q 2002*
VIS/IR Images	OCTS, AVNIR, POLDER	AVHRR-3	AVHRR-3	VIRS, LIS	MODIS, ASTER, MISR	Data Purchase	GLI	AATSR, MERIS	AVHRR-3		MODIS	AATSR, AVHRR-3		
Radiation Budget	POLDER			CERES	CERES (dual)			SCARAB			CERES (dual)	SCARAB		
Passive Atmospheric Sounding		AMSU-A1/2, AMSU-B, HIRS-3	AMSU-A1/2, AMSU-B, HIRS-3				AMSR		AMSU-A1/2, AMSU-B, HIRS-3		AIRS, AMSU, MHS	AMSU-A1/2, MHS, IASI, HIRS-3		
Passive Microwave				TMI			AMSR				MIMR	MIMR		
Active Microwave	NSCAT			PR			NSCAT II	ASAR				ASCAT	TMR	
Tropospheric Chemistry	IMG				MOPITT		IMG-2	SCIAMACHY					GLAS	HIRDLS
Stratospheric Chemistry	TOMS, ILAS	SBUV-2						GOMOS, SCIAMACHY, MIPAS	SBUV-2	SAGE III		GOMI		SAGE III, HIRDLS, MLS
Tropospheric Wind Lidar														
Altimeter								RA-2					SSALT	
Laser Ranging and Sounder													GLAS	
Other	RIS				DAS			PRAREE			DAS	MCP, DCS	DORIS	SOLSTICE II, ACRIM
Operational Instruments		AVHRR-3, AMSU-A1/2, AMSU-B, HIRS-3, SBUV-2, SEM, ARGOS, S&R	AVHRR-3, AMSU-A1/2, AMSU-B, HIRS-3, SEM, ARGOS, S&R						AVHRR-3, AMSU-A1/2, AMSU-B, HIRS-3, SBUV-2, SEM, ARGOS, S&R			AVHRR-3, AMSU-A1/2, MHS, SEM, S&R, HIRS-3, ARGOS+		

NASA will provide the NSCAT and TOMS instruments as the U.S. contribution to the payload, and will acquire ADEOS data directly at its ground station in Fairbanks, Alaska. After the first 6 months of mission operations, data will be collected on a routine basis for NOAA at NASA's Wallops Flight Facility (WFF). The conceptual design of the ADEOS follow-on—ADEOS II—is still underway. One proposal calls for dividing ADEOS II into two separate missions, with the first satellite to be launched in 1999. ADEOS II would carry a global monitoring payload, while an ADEOS II follow-on would have high-resolution visible and microwave sensors. Plans call for NASA to provide NSCAT II for the first ADEOS II payload.

The TRMM satellite, which will fly in a 35° inclination orbit, will be launched in August 1997. The payload will be provided jointly by NASDA and NASA. NASA will provide the TRMM spacecraft, the TRMM Microwave Imager (TMI), the Visible Infrared Scanner (VIRS), the Lightning Imaging Sensor (LIS), a radiation budget instrument (i.e., CERES), and instrument integration. Japan is providing the Precipitation Radar (PR) and launch on an H-II ELV. A TRMM follow-on (TRMM-2) is being proposed for launch in 2000, into a 55° inclination orbit.

With regard to EOS, MITI is providing ASTER for flight on EOS-AM1. In addition, an as yet to be determined Japanese instrument will be accommodated on the EOS-CHEM series. Japan is also sponsoring one of the EOS Interdisciplinary Science Investigations (see page 121).

CANADA

CSA is providing MOPITT for flight on EOS-AM1 and possible reflight on EOS-AM2. This instrument will measure atmospheric carbon monoxide and methane. CSA is also sponsoring two EOS Interdisciplinary Science Investigations (see pages 107 and 128).

OTHER

Other international investigators were selected by NASA through the EOS Announcement of Opportunity. Principal Investigators for Interdisciplinary Science Investigations were chosen from Brazil and Australia (see pages 105, 112, and 117). Co-investigators for the science investigations and EOS instrument team members represent 10 countries. These international EOS investigators are funded by their respective national agencies, but will have full access to observations acquired by EOS, and other services made available through EOSDIS.

The Graduate Student Fellowship in Global Change Research involves substantial international participation (see the Global Change Fellowship Program section). From 1990-1992, 33 fellowships have been awarded to foreign students, representing 18 countries. The total number of fellowships will increase prior to launch of the EOS satellites, thereby ensuring a pool of highly qualified Earth scientists to disseminate the data generated during the 15-year mission lifetime. ☆

INTERAGENCY COORDINATION

Interagency cooperation in the development and implementation of EOS continues to be extensive, especially among those agencies with space programs and/or significant responsibilities for archiving Earth science data. National Space Policy Directive 7 further cemented these agency relationships by establishing the Space-Based Global Change Observation System (S-GCOS) Program in June 1992. In tandem with other studies coordinated through USGCRP, S-GCOS will provide the global observations that help researchers understand the Earth as a system. The U.S. Government has placed S-GCOS in the forefront of USGCRP to ensure collection of comprehensive, integrated sets of consistent ground- and space-based observations; the space component of S-GCOS has Mission to Planet Earth as its centerpiece. NASA's Mission to Planet Earth Program has been planned to benefit from and complement the capabilities of its Federal partners, which are listed below, with specific roles in EOS development defined in the following paragraphs:

- Department of Commerce/National Oceanic and Atmospheric Administration (DOC/NOAA)
- Department of Defense (DoD)
- Department of Energy (DOE)
- Department of the Interior/U.S. Geological Survey (DOI/USGS).

Refer to the Mission Elements section for descriptions of the S-GCOS satellite and instrument contributions that fall under the rubric of the International Earth Observing System.

DEPARTMENT OF COMMERCE

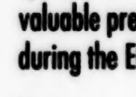
NOAA conducts U.S. civil programs for operational Earth remote sensing. Since 1960, satellite observations of the global environment have been provided by NOAA's POES system. Coverage of the Western Hemisphere has been provided by NOAA's Geostationary Operational Environmental Satellite (GOES) system since 1974. The current and future satellites of the POES and GOES systems are an essential part of USGCRP. These satellites provide valuable precursor data, and will yield complementary observations during the EOS mission lifetime. Furthermore, NOAA's long-term data record will be used to establish baseline conditions and to detect trends.

The present POES Program maintains two operational satellites in polar orbit—one providing morning (AM) coverage and the other afternoon (PM) coverage. The U.S. and Europe (i.e., EUMETSAT and ESA) have agreed in principle that Europe will take over responsibility for the AM global coverage mission in the 2000 time frame. NOAA will provide AM coverage through 2000, and will continue PM coverage. Through NOAA, the U.S. will provide a suite of four primary sensors for the European AM mission. EUMETSAT and others will reciprocate by supplying sensors and subsystems for flight on both the AM and PM satellites.

Planning for the cooperative program of global coverage by the U.S. and Europe includes arrangements to fly the NOAA/EUMETSAT operational payload in morning orbit and EUMETSAT's establishment of a high-latitude ground station to read out data from both the AM and PM platforms. This latter agreement ensures that data are downlinked each orbit, minimizing data latency and dependence on data averaging. With one European and two U.S. high-latitude stations, NOAA and EUMETSAT will essentially eliminate data delays associated with the recording of multiple or "blind" orbits. NOAA and EUMETSAT have agreed to establish systems and procedures to ensure the timely and full exchange of operational mission data.

Long-term improvements in NOAA satellite, instrument, and space subsystem design are expected to result from technology advances associated with the EOS Program. To this end, coordination in technology development extends to NASA designating some EOS instruments as "prototypes" for future operational environmental satellites. This means that NOAA and NASA are agreeing on design features that would enable these prototypes to be transferred to NOAA spacecraft after being space-proven in NASA research/demonstration efforts.

Data products derived from POES and GOES observations are provided to users in real-time and from archived data sets by NOAA; in addition, Pathfinder data sets are provided jointly by NASA and NOAA (see the Pathfinder Data Sets section). As a participant in the EOSDIS Program, NOAA will serve as the long-term archive for a



major portion of EOS data, and will continue to make available *in situ* data from its data centers. NOAA actively participates in EO-ICWG and the Committee on Earth Observations Satellites (CEOS); in addition, NOAA chairs the Interagency Working Group on Data Management for Global Change (IWGDMGC), where interagency data exchange arrangements and policies are planned and coordinated.

DEPARTMENT OF DEFENSE

DoD's Defense Meteorological Satellite Program (DMSP) maintains satellites in polar orbit to gather global environmental data. DMSP data and derived products have been made available to non-DoD users through NOAA. DoD will continue DMSP into the foreseeable future, and DMSP data will be available to global change researchers in standard formats via global change data networks.

In addition, responsibility for Landsat program management was assigned to the NASA Administrator and the Secretary of Defense by the Land Remote-Sensing Policy Act of 1992 (PL 102-555). This Act stipulates that NASA and DoD are to proceed with the procurement, launch, and operations of Landsat-7—providing data continuity with and beyond Landsat-6, which is scheduled for launch in 1993. The Act provides for the orderly transfer of Landsat responsibilities from the Secretary of Commerce to the NASA-DoD Landsat Program Management Team, as well as the requirement for a program of research, development, and demonstration of advanced land remote-sensing technology. The Landsat Program Management Team awarded a contract for Landsat-7 in the fall of 1992; a research and development program plan to demonstrate new technologies is currently being prepared.

DoD plans future satellites and instruments that will provide additional Earth system observations. Missions under consideration address ocean conditions, ozone and trace gas distributions, ionospheric airglow, and solar energy interactions with the atmosphere. DoD participates in planning for USGCRP and its associated data systems. In cooperation with the other Federal agencies involved in EOSDIS and related data systems, DoD is seeking workable approaches to make more of its relevant data available. Other working groups are being established to explore potential environmental remote-sensing collaborations between NASA and DoD.

DEPARTMENT OF ENERGY

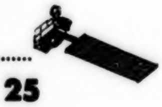
DOE develops and uses remote-sensing technology in many of its programs. The agency develops and tests climate models, and assesses the impacts associated with incidental environmental forcing functions. For instance, DOE has conducted a decade-long program to improve general circulation models and to provide reliable predictions of regional climate change in response to increases in atmospheric greenhouse gases. DOE holds databases acquired from a multitude of sources as tools for conducting its modeling and climate-prediction activities.

With respect to hardware, DOE has successfully miniaturized key components of space-based instrumentation, which adds a great deal of flexibility to Earth remote-sensing programs. Recent developments now enable the deployment of low-mass, low-volume sensors on conventional or small satellites. Miniaturization technology contributes to the effectiveness of USGCRP by allowing early deployment of small satellites. In an effort to exploit such technology advances, NASA and DOE have created a Joint Development and Demonstration Program in Advanced Remote-Sensing Technology, which has the objective of lowering the cost and improving the performance of remote sensors. The ultimate goal involves the development of remote-sensing technologies and concepts for space-based environmental applications. Four areas are currently under investigation: Laser detection of winds, high-resolution multispectral imaging, synthetic aperture radar, and unmanned aerospace vehicle (UAV) sensing.

Along with the involved U.S. agencies, DOE is developing the networking capabilities to make its current and future global change archives more conveniently accessible to users. In the EOSDIS framework, DOE has agreed to manage the EOS biogeochemical dynamics database, and data from coordinated field experiments. This database will reside at the Oak Ridge National Laboratory (ORNL).

DEPARTMENT OF THE INTERIOR

Management responsibility for the Nation's natural ecosystem, energy and water resources, and public lands is vested in DOI. Within DOI, USGS is addressing the collection, maintenance, analysis, and interpretation of *in situ* short- and long-term land, water,



biological, and other natural resource data and information. USGS is developing advanced information systems to provide enhanced access to existing and future archives of Earth science data through its primary archive for global change data—the Earth Resources Observation System (EROS) Data Center (EDC).

EDC houses the world's largest collection of space- and aircraft-based imagery of the Earth's land surface, including over 2 million images acquired from Landsat and other satellites, and over 8 million aerial photographs. As part of the EOS Program, EDC is responsible for the following:

- Operating the data center responsible for land processes information
- Communicating with the EOS science and instrument teams to ensure delivery of land-related products required for EOS investigations
- Linking the USGS Global Land Information System (GLIS) to the EOSDIS Information Management System (IMS). GLIS—an on-line data directory, guide, and inventory system—is being developed by USGS to respond to the land data and access needs of the global change research community.

By the time of EOS-AM1 launch in 1998, Landsat data housed at EDC will provide a 25-year baseline of information about land surface conditions and changes. As the operator of the National Satellite Land Remote-Sensing Data Archive, USGS has embarked upon a major program to convert the Landsat data archive to next-generation durable storage media, thereby avoiding loss of data stored on deteriorating magnetic tapes. In addition, EDC will serve as the processing, distribution, and archival facility for Landsat-7 data. ☆

EOS DATA AND INFORMATION SYSTEM (EOSDIS)

EOSDIS will manage the data resulting from NASA's Earth science research satellites and field measurement programs, and other data essential for the interpretation of these measurements. EOSDIS will supply data archive, distribution, and information management services; for EOS satellites, EOSDIS will also provide data product generation and command and control functions. EOSDIS will provide data sets generated by assimilation of applicable observations into global climate models. To this end, EOSDIS must perform a wide variety of functions, supporting individuals located in various organizations and carrying on several distinct types of activity, including:

- Mission planning, scheduling, and control
- Instrument planning, scheduling, and control
- Resource management
- Communications
- Computational facilities at investigator sites
- Generation of standard data products
- Generation of special data products
- Archiving of data, products, and research results
- Data and information cataloging, searching, browsing, and ordering
- Effective distribution of all information holdings
- User support.

These groupings of functions and activities together with their interrelationships are illustrated in Figure 7. Multiple boxes indicate distributed capabilities. For instance, data use in research, algorithm development and maintenance, and data product generation, archiving, and distribution are carried out in many different locations, while mission planning, scheduling, and control take place at one site [i.e., the EOS Operations Center (EOC)].

EOSDIS COMPONENTS

NASA is implementing EOSDIS using a distributed, open system architecture. This allows for the distribution of EOSDIS elements to various locations to take best advantage of different institutional capabilities and science expertise. Although EOSDIS is physically distributed, it will appear a single logical entity to the user. EOSDIS will consist of an EOSDIS Core System (ECS) to provide centralized mission and instrument command and control functions, and distributed (but common) product generation, archive, and information management functions. Capabilities also exist outside of the core, including site-unique extensions to core capabilities, computing facilities for EOS researchers, and so on. As can be seen in Figure 7, the EOSDIS architecture is composed of several types of elements, most of which will be geographically distributed, thereby providing a resilient program. The following paragraphs provide details on each of the components making up the data system. They should not be considered a prioritized ranking; rather, each function proves invaluable in the successful implementation of EOSDIS.

Internal and External Networks. The large, distributed community of Earth scientists and other users requires large network capacity and broadly available, easy connectivity. This is the function of the EOSDIS External Network. In implementing the external network, NASA is currently using NASA Science Internet and its connections to the National Science Foundation (NSF) Internet, and will make maximum use of the National Research and Education Network (NREN) as it develops. The interconnection of the EOSDIS elements requires a secure, high-bandwidth network functioning in a controlled manner to enable the various elements to support one another in a timely fashion and to support communication with the satellites. The EOSDIS Internal Network will meet these requirements. Figure 8 illustrates the internal and external network connections that must be made, but not necessarily the actual architecture of backbone and tail circuits.

Science Computing Facilities (SCFs). After networks, the key item determining the nature of EOSDIS access will be the type of equipment required to support the user interface. For the primary user community of environmental researchers, SCFs will provide this capability. SCFs will range from personal workstations to supercomputers supporting algorithm development and other EOSDIS functions. To

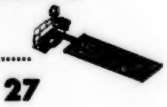
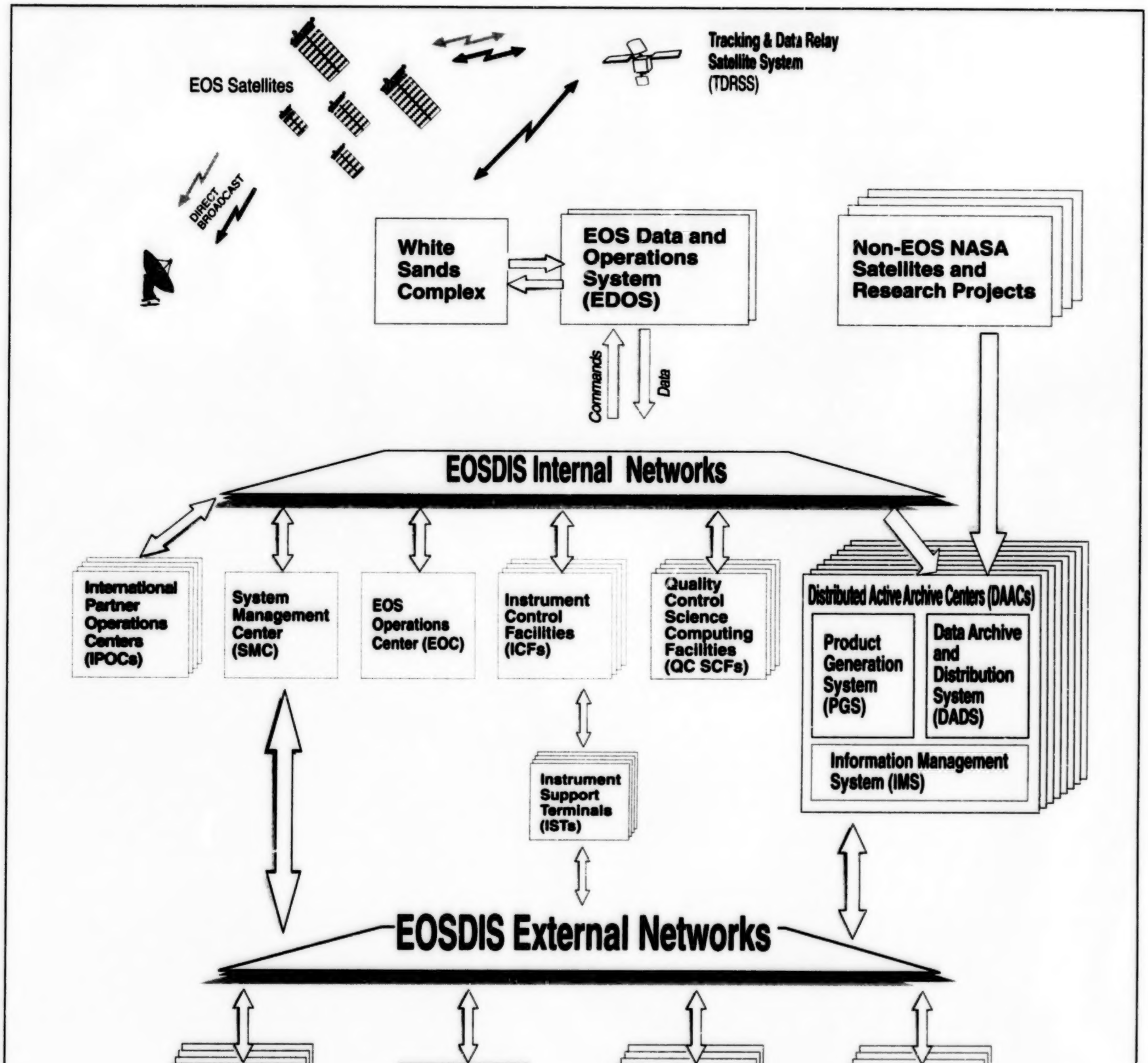
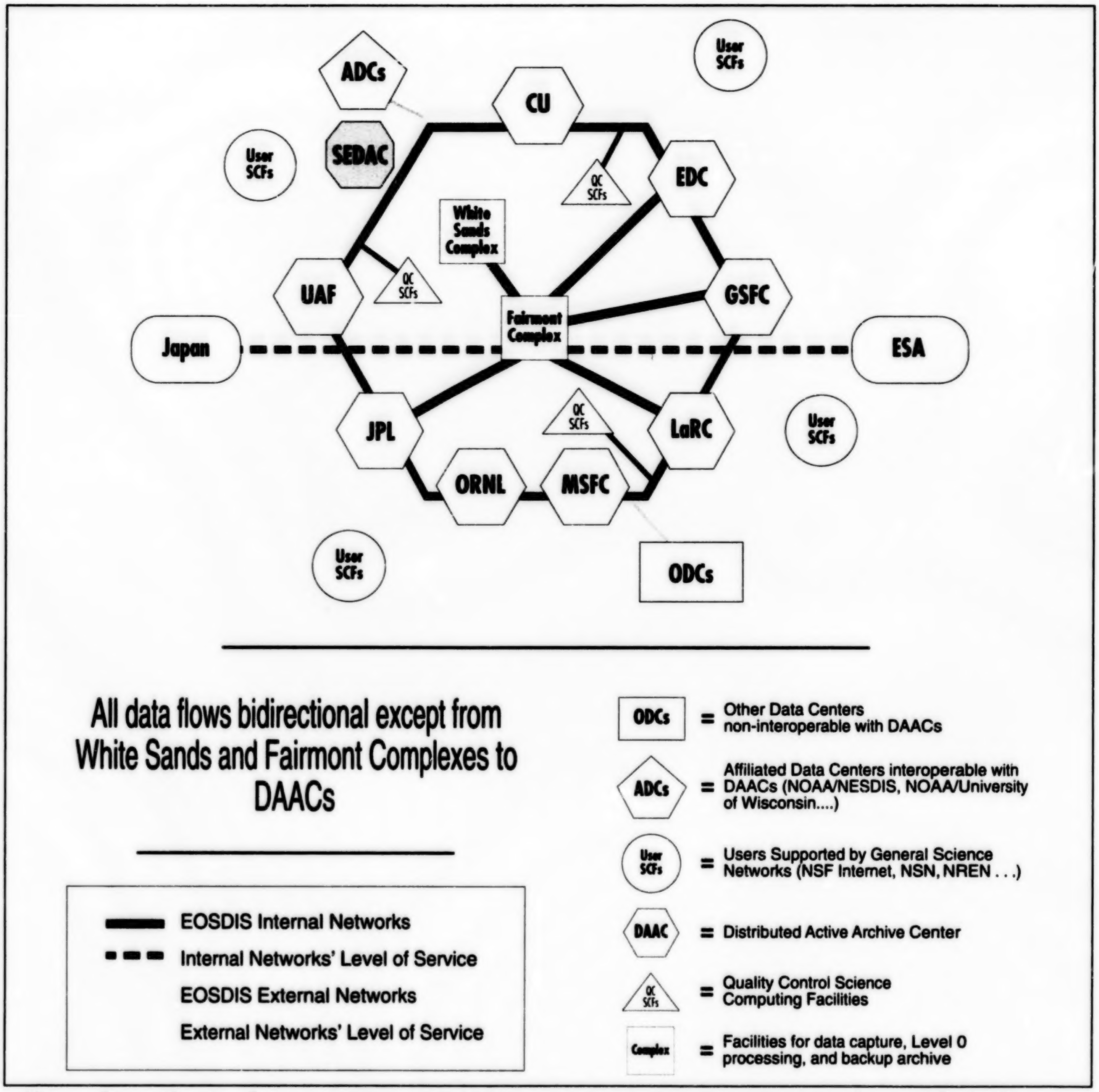


Figure 7. EOSDIS Architecture


EOS Satellites
Tracking & Data Relay Satellite System (TDRSS)
DIRECT BROADCAST
White Sands Complex
EOS Data and Operations System (EDOS)
Non-EOS NASA Satellites and Research Projects
Commands
Data
EOSDIS Internal Networks
International Partner Operations Centers (IPOCs)
System Management Center (SMC)
EOS Operations Center (EOC)
Instrument Control Facilities (ICFs)
Quality Control Science Computing Facilities (QC SCFs)
Distributed Active Archive Centers (DAACs)
Product Generation System (PGS)
Data Archive and Distribution System (DADS)
Information Management System (IMS)
Instrument Support Terminals (ISTs)
EOSDIS External Networks
Affiliated Data Centers (ADCs)
SEDAC
PGS
DADS
IMS
User Science Computing Facilities (SCFs)
OTHER USERS


ADCs
CU
User SCFs
User SCFs
SEDAC
QC SCFs
EDC
White Sands Complex
UAF
QC SCFs
GSFC
Fairmont Complex
Japan
ESA
JPL
QC SCFs
LaRC
User SCFs
ORNL
MSFC
User SCFs
ODCs
EOSDIS Internal Networks
Internal Networks' Level of Service
EOSDIS External Networks
External Networks' Level of Service
ODCs = Other Data Centers non-interoperable with DAACs
ADCs = Affiliated Data Centers interoperable with DAACs (NOAA/NESDIS, NOAA/University of Wisconsin....)
User SCFs = Users Supported by General Science Networks (NSF Internet, NSN, NREN . . .)
DAAC = Distributed Active Archive Center
QC SCFs = Quality Control Science Computing Facilities
Complex = Facilities for data capture, Level 0 processing, and backup archive

All data flows bidirectional except from White Sands and Fairmont Complexes to DAACs

Figure 8. EOSDIS Networking Strategy

enable access from a wide variety of researchers, EOSDIS will make available to users software toolkits that can be run on computers readily affordable within typical research grants. These toolkits will facilitate access to EOSDIS services and, in some cases, allow local provision of EOSDIS services. EOSDIS will provide access and as many services as possible to users who possess as little as a personal computer and modem. Many other sources, both within and external to NASA, will provide research funding for computing equipment and communications to support the needs of the Earth science community.

Quality Control (QC) SCFs. QC SCFs will include special software to enable investigators responsible for standard product algorithms to perform scientific quality control of their products. Located at the investigators' home institutions, these SCFs will be connected to the EOSDIS internal network.

Distributed Active Archive Centers (DAACs). Eight DAACs covering various types of Earth science data have been selected by NASA to carry out the responsibilities for processing, archiving, and distributing EOS and related data and for providing a full range of user support. These institutions ensure that data will be available indefinitely in an easily usable form. Acting in concert, DAACs will support global change researchers whose needs cross traditional discipline boundaries, while continuing to support the particular needs of the discipline community. DAAC assignments were based primarily on the current distribution of scientific expertise and institutional heritage and capability (see Figure 9); the planned responsibilities of these centers are listed in Table 8. Each EOS DAAC contains functional elements that include a Product Generation System (PGS), a Data Archive and Distribution System (DADS), and an Information Management System (IMS). These elements include a common "core" set of functions provided by the distributed ECS, and also some DAAC-unique extensions required to support each DAAC's discipline user community. Other Federal agencies may share management and funding responsibilities for the active archives under terms of agreements negotiated with NASA. During the EOS operational lifetime and beyond, NASA may make arrangements to transfer responsibility for some or all EOS data and products from EOS active archives to permanent archives.

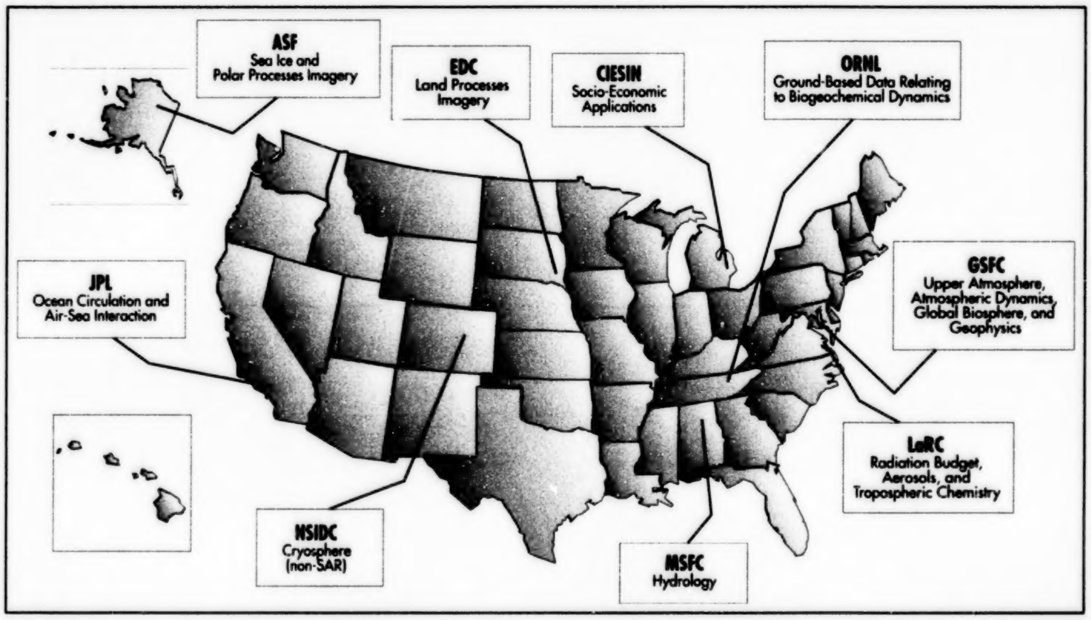

ASF
Sea Ice and Polar Processes Imagery
EDC
Land Processes Imagery
CIESIN
Socio-Economic Applications
ORNL
Ground-Based Data Relating to Biogeochemical Dynamics
JPL
Ocean Circulation and Air-Sea Interaction
GSFC
Upper Atmosphere, Atmospheric Dynamics, Global Biosphere, and Geophysics
LaRC
Radiation Budget, Aerosols, and Tropospheric Chemistry
NSIDC
Cryosphere (non-SAR)
MSFC
Hydrology

Figure 9. Geographical Distribution of EOSDIS

Socio-Economic Data and Applications Center (SEDAC). An additional center—Consortium for International Earth Science Information Network (CIESIN)—receives funding from NASA to act as a link between the EOS Program and the socio-economic/educational user community. The data acquisition, processing, archival, and data distribution functions at CIESIN are similar to those carried out by the eight DAACs; however, SEDAC is connected to EOSDIS only via the external network. Figures 7 and 8 illustrate the role of CIESIN within the overall framework of EOSDIS.

EOS Data and Operations System (EDOS). This distributed component of EOSDIS provides for command uplink and data capture through NASA's Tracking and Data Relay Satellite System (TDRSS) at the White Sands Complex in New Mexico, and production processing of EOS data at a facility in Fairmont, West Virginia. Production processing involves the separation of composite downlink transfer frame data streams into individual payload/instrument data packet streams (i.e., Level 0 processing). EDOS also provides a long-term backup archive of the Level 0 processed data. The uplinking of commands to and the acquisition of Level 0 data from EOS instruments on the international partner satellites will be handled via interfaces to the respective ground systems.

EOS Operations Center (EOC). This center is responsible for mission control, mission planning and scheduling, instrument command support, and mission operations. All communications with the platforms and instruments go through EOC.

International Partner Operations Centers (IPOCs). These centers perform functions similar to those of EOC for the international partner observatories.

System Management Center (SMC). In coordination with the DAACs, SMC ensures appropriate data flows, and manages production schedules and resource usage. Its functions include configuration management; high-level scheduling of system, site, and element activities; monitoring of production and performance; resolving faults; security; and accounting and billing.

Instrument Control Facilities (ICFs). These facilities consist of several Instrument Control Centers (ICCs). Each ICC plans and schedules instrument operations, generates and validates command sequences, provides the capability to forward commands and to store them for later transmission, monitors the health and safety of instruments, and provides instrument controllers with status information on their instruments. The international partner ICCs will perform similar functions for their instruments on EOS spacecraft.

Instrument Support Terminals (ISTs). Residing at Instrument PI and Team Leader sites, ISTs are used to access ICCs for information on the health and safety of individual instruments. They enable PIs and their engineering support teams to provide command inputs to the ICCs, and to participate with instrument and mission controllers in the diagnosis and resolution of performance anomalies.

Field Support Terminals (FSTs). FSTs will provide mobile communications to coordinate platform data acquisition with field experiments and the necessary display capabilities to support field campaigns.

Table 8. EOSDIS-Sponsored Data Centers

Center	Initial Systems	Discipline Responsibilities	EOS and Other Missions/Instruments
Distributed Active Archive Centers			
GSFC Goddard Space Flight Center	NCDS, PLDS, CDDIS	Upper atmosphere, atmospheric dynamics, global biosphere, and geophysics	AIRS/AMSU/MHS, CZCS, GLAS, HIRDLS, MIMR, MLS, MODIS, SAGE III, SeaWiFS, TOMS, and TMI
LaRC Langley Research Center	ERBE processing	Radiation budget, aerosols, and tropospheric chemistry	ACRIM, ASTER, CERES, EOSP, ERBE, MOPITT, MISR, SAGE III, SOLSTICE II, and TES
EDC EROS Data Center	GLIS, Landsat processing	Land processes imagery	ASTER, AVHRR, Landsat (MSS and TM), MISR, SAR (land), and airborne sensors
UAF University of Alaska–Fairbanks	ASF system	Sea ice and polar processes imagery	ERS-1, JERS-1, ERS-2, Radarsat, and ongoing role as ground station
CU University of Colorado	CDMS	Cryosphere (non-SAR)	DORIS, GLAS, MIMR, SSALT, OLS, SMMR, and SSM/I
JPL Jet Propulsion Laboratory	NODS	Ocean circulation and air-sea interactions	MIMR, NSCAT, Seasat, SSALT, and TMR
MSFC Marshall Space Flight Center	WetNet	Hydrology	MIMR, TMI, PR, LIS, and SSM/I
ORNL Oak Ridge National Laboratory	TGDDIS	Biogeochemical dynamics	*In situ* trace gas and gas flux data
Socio-Economic Data and Applications Center			
CIESIN Consortium for International Earth Science Information Network	—	Human dimensions of global change and policymaking applications	Socio-economic data

Product Generation System (PGS). This DAAC element performs data processing functions, including routine generation of standard products, quick-look products, metadata, and browse data sets. These operations also extend to reprocessing of data and retrospective production of new standard products. Computational support for other activities, including research and special product trials, can also be included in these facilities.

Data Archive and Distribution System (DADS). This DAAC element is responsible for archiving and distributing EOS data and information, including Level 0 and higher data products, ancillary and correlative data, metadata, command histories, algorithms, and documentation. Data will be distributed from DADS to EOS scientists, other EOS facilities, and other research users electronically via networks or on high-density storage media (e.g., optical disks), depending on the requested volume.

Information Management System (IMS). As the user interface, IMS provides information about EOSDIS data holdings on a 24-hour basis; provides pointers to external archives with which EOSDIS interoperates; accepts user orders for EOS data; provides information about future data acquisition and processing schedules; accepts and forwards data acquisition and processing requests; and maintains information on system status, management, and coordination. The IMS will be distributed to individual DAACs; however, in keeping with the transparent user interface, researchers accessing IMS will see the same comprehensive "Earth science" view of the overall EOSDIS database, spanning the holdings of all the DAACs.

Affiliated Data Centers (ADCs). These non-EOS data centers will provide special access to non-EOS data or to special non-EOSDIS services required by the EOS Program. Examples of planned ADCs include NOAA/National Environmental Satellite, Data, and Information Service (NESDIS) national data centers, and the NESDIS GOES archive at the University of Wisconsin.

A Permanent Archive. Funded independent of the EOS budget, this type of facility may take responsibility for the permanent archiving and user services for EOS data and products during and beyond the scope of the EOS mission. Agreements with these archives will be negotiated by NASA Headquarters, with EOS Project coordination, and these agreements will become part of the EOS Project Data Management Plan. Examples of permanent archives include USGS/EDC and NOAA/NESDIS.

EOSDIS EVOLUTION

User needs for EOSDIS will become more clearly understood as researchers work with and respond to early versions of the system; undoubtedly, user needs will change over time. New information systems technology will continually emerge, including new database and information management technology applicable to Earth science data as well as faster processors and more capable networks. To succeed over its lifetime, EOSDIS must be responsive to change; its design and the implementation process must facilitate change even while supporting ongoing operations and user services. Development and prototyping will continue throughout the life of the system.

The EOSDIS design will maximize openness to change through the incorporation of layering and standards, and vendor independence to the fullest extent possible. The prototyping program will allow new features, functions, and implementations of new technology to be tested and evaluated in a near-operational setting, with successful prototypes implemented in the operational EOSDIS. EOSDIS evolution has already begun with work on Version 0, and will continue with the subsequent versions described below.

EOSDIS Version 0. This working prototype (with some operational elements) is being developed between 1991 and 1994. This system interconnects existing Earth science data systems via electronic networks, interoperable catalogs, and common data distribution procedures to provide better access to existing and pre-EOS data. Starting with existing heterogeneous Earth science data systems, Version 0 will evolve toward the full EOSDIS by taking maximum advantage of existing experience and by ensuring that no disruption in current user services occurs. Through interconnection of the existing systems, Version 0 serves as a functional prototype of selected key EOSDIS services. As a prototype, it does not have all the capabilities, fault tolerance, or reliability of later versions; however, EOSDIS Version 0 supports use by the scientific community in day-to-day research activities. Such use tests existing services to determine what additional or alternative capabilities are required of the full EOSDIS. Operational use of Version 0 is expected in mid-1994.

EOSDIS Version 1. This version will be implemented in steps over the 1995-1997 time frame. It will be designed and developed while Version 0 is operating, thus benefiting from Version 0 user feedback. Version 1 will be physically distributed, but the system will appear completely integrated to users and will provide researchers with the complete set of capabilities needed for EOS science and mission operations. The new capabilities of the Version 1 data and information system will progressively replace (after a period of parallel operations) the Version 0 system to provide smooth and transparent transition to enhanced services.

EOSDIS Version 2. EOSDIS Version 2 will be implemented before launch of the first EOS satellite in 1998. The mission and instrument command and control functions and product generation functions discussed above will be greatly enhanced, and full capacity will be available to support all functions for the first EOS platform.

Subsequent versions of EOSDIS will supplement capacity and services as required by EOS spacecraft launches. EOSDIS capabilities will be evaluated continually by the research community, and technology will be refreshed or augmented as the need arises.

KEY EOSDIS TERMINOLOGY

Standard Data Products. Data products that are generated as part of a research investigation using EOS data, are of wide research utility, are routinely generated, and in general are produced for spatially and/or temporally extensive subsets of the data are to be considered standard data products. All EOS instruments must have standard Level 1 data products, and most will have standard Level 2 data products. Some EOS Interdisciplinary Science Investigations will also generate standard data products. Specifications for the set of standard data products to be generated by the EOS Project will be reviewed continuously by EOS IWG and NASA Headquarters to ensure completeness and consistency in providing a comprehensive science data output for the EOS mission. Standard data products will normally be generated in the EOS PGS elements. The list of data products to be available prior to launch of the various EOS platforms is currently under revision, and will be included in the 1994 edition of the EOS Reference Handbook.

Special Data Products. Data products that are generated as part of a research investigation using EOS data and that are produced for a limited region or time period, or products that are not accepted as standard by EOS IWG and NASA Headquarters, are referred to as special data products. Special data products will normally be generated at investigator SCFs. Special products may be reclassified later as standard products upon review and approval by EOS IWG and NASA Headquarters; in which case, the algorithms and processing will migrate to the PGS elements and be placed under the appropriate configuration controls.

Level Definitions. The various levels of data referred to in this document are identical to those defined by the EOS Advisory Panel in its report and are consistent with the Committee on Data Management, Archiving, and Computing (CODMAC) definitions. For some instruments, there will be no Level 1B product that is distinct from the Level 1A product. In these cases, the reference to Level 1B data can be assumed to refer to Level 1A data. Brief definitions follow:

- Level 0—Reconstructed unprocessed instrument/payload data at full resolution; any and all communications artifacts (e.g., synchronization frames, communications headers) removed
- Level 1A—Reconstructed unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (i.e., platform ephemeris) computed and appended, but not applied, to the Level 0 data
- Level 1B—Level 1A data that have been processed to sensor units (not all instruments will have a Level 1B equivalent)
- Level 2—Derived geophysical variables at the same resolution and location as the Level 1 source data
- Level 3—Variables mapped on uniform space-time grid scales, usually with some completeness and consistency
- Level 4—Model output or results from analyses of lower level data (i.e., variables derived from multiple measurements). ☆

PATHFINDER DATA SETS

The Pathfinder data set concept was initiated by the EOS Program Office at NASA Headquarters in answer to the question "What can be done now to further global change research?" Pathfinders will provide access to large remote-sensing data sets applicable to global change research prior to the availability of data from the EOS satellites. From these long time-series of global and/or regional data sets, higher level geophysical products will be derived in support of USGCRP objectives. The main goal of the Pathfinder Program is to make research-quality global change data sets easily available to the Earth science community. Of course, experience gained in processing/reprocessing, archiving, and distributing standard scientific data products proves a boon as well. As scientific understanding develops and product retrieval algorithms are improved, these data sets may require additional reprocessing, which would be provided by this program.

All Pathfinder data sets involve space-based observations, and are subject to the following requirements: 1) Stable calibration of the raw data should be attainable; 2) when data from multiple instruments are involved, consistent intercalibration among instruments in a series should be possible; and 3) archive may include transferring the data to a more accessible medium. Pathfinder activities include reprocessing of these data using community-consensus algorithms as recommended by designated Science Working Groups (SWGs). The resultant data sets will be available through DAACs under EOSDIS Version 0.

A Benchmark Period (April 1987 to November 1988) has been chosen to facilitate complementary analyses and intercomparison studies. Wherever possible or applicable, Pathfinder data processing will begin with this time period. In pursuit of the most efficient processing method, different procedures may take place at separate facilities, requiring data transfer among them.

In October 1990, NOAA and NASA signed an agreement establishing three joint NASA/NOAA Pathfinders to be generated from existing NOAA data sets, as follow:

- Advanced Very High-Resolution Radiometer (AVHRR) Global Area Coverage (GAC) data held by NOAA
- Television Infrared Observing Satellite (TIROS) Operational Vertical Sounder (TOVS) data held jointly by NOAA and NASA
- Geostationary Operational Environmental Satellite (GOES) data held by the University of Wisconsin under contract with NOAA.

In 1991, the Special Sensor Microwave/Imager (SSM/I) data set was added as a NASA/NOAA Pathfinder. SSM/I data are currently archived by NOAA under a Shared Processing Agreement with the Navy and the Air Force. Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data—held primarily by USGS/EDC—were added to the Pathfinder activity in 1992. The Landsat Pathfinder effort involves NASA, EPA, and USGS. Also in 1992, NASA's Scanning Multispectral Microwave Radiometer (SMMR) data set was added as the first NASA-only Pathfinder. Other existing data sets are currently being evaluated to determine their utility within the overall objectives of the multiagency Pathfinder Program.

One or more SWGs have been formed for each of the identified data sets to provide recommendations for specific Pathfinder activities. SWG reports to the involved partner agencies consist of the following:

- Determination of the scientific needs for Pathfinder data and how these needs translate into specific products
- Identification of community-consensus algorithms for generating Pathfinder products and determination of the data required to generate these products
- Recommendation on how these products are to be generated, validated, stored, and maintained
- Identification of the data services required by users of Pathfinder data (including catalog and browse functions, metadata, and data access).

Pathfinder data products will be treated as new data sets and will be archived at one or more EOSDIS DAACs according to discipline responsibilities. Copies will also be archived by the collaborating agencies. Table 9 lists the current Pathfinder efforts and the DAACs currently planning to house the reprocessed data.

AVHRR Pathfinder scientific data products consist of global vegetation and radiance data for the land community, global sea-surface temperature data for the ocean community, and global clouds, radiation, and aerosols data for the atmospheric sciences community.

These data are produced from GAC observations made by the five-channel AVHRR instruments onboard NOAA-7/9/11, and will cover the time period of mid-1981 through 1992 and beyond. Processing of land, ocean, and atmosphere products is scheduled to begin in FY1993, with the land products processing beginning in February 1993. The AVHRR Level 1B GAC data that serves as the processing input (including new calibration tables designed to stabilize the calibration and provide inter-instrument calibration) are also a Pathfinder product. Transcription teams at NASA and NOAA have copied more than 30,000 magnetic tapes to almost 400 optical disks, each holding 6 GB of data. This effort was completed at the end of 1992.

A Pathfinder study concerning the quality of existing GOES data has been completed, and a summary report is being prepared. An intensive development effort is underway at the University of Wisconsin's Space Science and Engineering Center (SSEC) to create a product generation system that can ingest data at 3.6 times the present real-time capability. Initial GOES Pathfinder product generation will begin in the spring of 1993.

A TOVS implementation team meeting was held in June 1992. A set of geophysical parameters for specific spatial/temporal scales was selected for inclusion into the NOAA-10 Benchmark Period data set. In addition, it was decided that the Level 3 products from the first month of the period (i.e., April 1987) will be used as a quality check using three distinct processing methodologies: Path A at GSFC, Path B at the Laboratoire de Meteorologie Dynamique/Atmospheric Radiation Analysis Group (LMD/ARA) at Ecole Polytechnique in Paris, France, and Path C at both NOAA/NESDIS and Marshall Space Flight Center (MSFC). Thereafter, the remaining 19 months of the Benchmark Period data will be processed by the four teams by September 1993, for intercomparison and validation of the results. The GSFC DAAC will archive and distribute final products.

Table 9. Pathfinder Data Availability

Data Set	DAAC (Discipline Focus)
AVHRR Advanced Very High-Resolution Radiometer	GSFC (Atmosphere, Land) JPL (Ocean)
TOVS TIROS Operational Vertical Sounder	GSFC (Atmosphere)
GOES Geostationary Operational Environmental Satellite	University of Wisconsin (ADC) LaRC (Clouds and Radiation)
SSM/I Special Sensor Microwave/Imager	MSFC (Hydrology) JPL (Ocean) NSIDC (Cryosphere)
SMMR Scanning Multispectral Microwave Radiometer	MSFC (Hydrology) JPL (Ocean) NSIDC (Cryosphere)
Landsat Land Remote-Sensing Satellite	EDC (Land)

The SSM/I Pathfinder will create a suite of products at both Levels 2 and 3. The Level 1 antenna temperatures will be converted to Hierarchical Data Format (HDF), and the swath products will be generated at MSFC beginning in February 1993; the Level 3 gridded products will be generated at the National Snow and Ice Data Center (NSIDC) in July 1993. Archive of the product suites will vary by discipline interest in specific products. A CD-ROM containing selected products is planned for early distribution.

The goal of the Landsat Land Cover Pathfinder effort is to establish long-term, medium- to high-resolution data sets for particular regional and global applications to global change research. The Landsat Pathfinder SWG has defined several projects to address land cover change. Within the Tropical Deforestation Project, NASA and EPA are funding selected universities to produce a 3-epoch forest/no-forest data set showing areas of deforestation, derived from each of the moist tropical forested regions (i.e., the Amazon, Central Africa, and Southeast Asia). EPA has taken the lead in a second project to produce 3 epochs of wall-to-wall coverage of conterminous North America. The Pathfinder Program expects to create additional data sets related to global change monitoring issues in such areas as biology, ecology, geology, hydrology, atmospheric sciences, and social sciences. Lastly, work is underway to compile time-series data sets of selected sites chosen because of historical data richness or for other characteristics contributing to global change research.

A Pathfinder Interuse Workshop was held in July 1992, to determine standards and to identify solutions to problems associated with formats, projections, resolution, and binning; the objective was to facilitate Pathfinder data product integration. The workshop resulted in the resolve to use, when possible, the EOSDIS Version 0 prototype standard (i.e., HDF) as the common data format. A smaller technical group is being formed to work intensively on the remaining problems of binning, resolution, and projection, with results expected in 1 to 2 years. ☆

DATA AND INFORMATION POLICY

The EOS data policy is designed to be consistent with the U.S. National Data Policy and to further the EOS objectives of acquiring a comprehensive global, long-term data set; maximizing data utility for scientific purposes; and simplifying access to and analysis of EOS data. A common set of data exchange principles will cover the Japanese, European, and U.S. missions comprising IEOS (see the International Cooperation and Mission Elements sections). In realizing this goal, NASA has adopted the following data policy:

- Data from EOS instruments will be acquired according to priorities recommended by IWG and EO-ICWG, and confirmed by NASA Headquarters.
- Where EOS sensors make site-specific observations, EOS will be an "acquire-on-demand" system. Data will only be taken in cases where there is an identified user who has requested and will analyze the data.
- All acquired EOS data will be processed at Level 0 or at a higher level from which Level 0 may be recovered.
- Raw data from instruments designated as having operational potential will be made available to NOAA as soon as they are received on the ground.
- Routine processing and reprocessing of EOS data by the EOS Project to standard products at Levels 2 and above will be done according to science requirements and using algorithms approved by IWG.
- Following the post-launch checkout period, all Level 0 data will be available within 21 hours of receipt on the ground. Level 1 standard products will be processed and made available by EOSDIS within 24 hours after the Level 0 input data are available; Levels 2 and 3 standard products will be made available within 24 hours after receipt of the required input data. These higher level products will be archived.
- EOS data and products will be available to all users; there will be no period of exclusive access.
- All data requests for approved research, non-commercial operational, and applications demonstration purposes will incur a modest charge consistent with the actual marginal costs of filling the request. This system will ensure reasonable allocation of EOSDIS resources, while not discouraging full use of EOS data. Data will be provided for other uses, including commercial activities, on the same time scales and at non-discriminatory prices and terms to be established by the relevant instrument provider and platform operator.
- EOSDIS will provide the capability for archiving and making available all science data products, models, algorithms, and documentation generated as part of the EOS mission. All products derived from EOS data provided for research purposes at the marginal cost of filling the user request, and which are the basis for refereed articles—including models, algorithms, and associated documentation—must be made available to the research community.
- EOSDIS will include and make available information about the data, such as quality assessments, supporting literature references, and catalog and directory entries.
- EOSDIS project management, in consultation with IWG, will establish protocols and standards to encourage and facilitate data software exchange and interoperability.

Four general categories of users are expected to access EOS data: Research users, including U.S. Government-sponsored and other researchers; non-commercial operational and environmental monitoring public sector agency users (e.g., NOAA and EUMETSAT); applications demonstrations (limited proof-of-concept resulting in a published technical report); and other users (primarily commercial).

Research Users. These users will be designated through an AO or similar mechanism based on a brief proposal describing the research activity. Designated research users, whether funded by the EOS Program or through other channels, must sign a "research agreement" and are granted access to the data appropriate for the proposed research from EOS and its foreign partner programs at no more than the marginal cost of filling the specific user request. The research agreement includes a brief description of the proposed research, and confirms that the data are to be used in a study or investigation 1) that aims to establish facts or principles; 2) where the data may not be sold, and may be reproduced or provided only to other researchers covered by a research agreement and for whom the researcher takes responsibility; 3) where the results of the research will be submitted for publication in the scientific literature; and 4) where detailed results—including data, algorithms, and models—will be made available to the research community at the time they are accepted for publication.

Public Sector Agency Users. Operational and environmental monitoring involves non-commercial routine use of data to carry out a mandate of environmental observation and prediction as part of an agency's responsibilities to provide for the general welfare. Such users include those Government agencies affiliated with the parties that conduct environmental monitoring and/or operational observations, and can include larger agencies to which the parties belong, such as the World Meteorological Organization (WMO). Operational agencies may obtain real-time access through their own direct readout facilities and/or via relay satellites, or as available from the appropriate data and information systems. Operational users may be asked to report periodically on their activities.

Applications Demonstrations. Users who fall into this category are involved in limited proof-of-concept studies to demonstrate new techniques or to test the feasibility of operational applications. Results of applications demonstrations must be published as technical reports and be provided to the data system that supplied the data. Data requests for applications demonstrations must include a brief proposal describing the intended use. Selected users will be required to sign an agreement confirming that the data will be used only for the proposed applications demonstration, that the data will not be used for commercial purposes, that the data will not be reproduced or provided to third parties without permission, and that the results will be published as a technical report.

Commercial Users. Commercial agreements will be established for each sensor or data set to serve users who do not fit into one of the above categories. Procedures will be in place prior to EOS launch for commercial distribution of all EOS data on a non-discriminatory basis for "other" users.

The data exchange principles described above will be included in each of the bilateral Memoranda of Understanding (MOUs) that NASA will have with its international partners, and a joint implementation plan is being developed to define the implementation of these principles in the participating agencies. ☆

GLOBAL CHANGE FELLOWSHIP PROGRAM

NASA has established the Earth System Science Education Program to enhance awareness, interest, and knowledge of Earth system science by teachers and students (preschool through graduate-student level), and the general public. As part of this program, NASA has promoted the Graduate Student Fellowship in Global Change Research.

The EOS budget contains a special fund earmarked for education in Earth system science. The Graduate Student Program in Global Change Research was established in 1990, to support graduate students pursuing a Ph.D. degree in Earth system science. Fellowships are awarded for an initial 1-year term and may be renewed annually for up to 2 more years, based on satisfactory progress as reflected in academic performance and evaluations made by faculty advisors. The amount of award is $20,000, which may be used as a stipend to defray living expenses, tuition, travel, books and supplies, and fees. An additional $2,000 is available by request for the faculty advisor's use in support of the student's research. A total of 37 fellowships were conferred in 1990, and 60 fellowships were awarded in 1991. In 1992, these fellowships were renewed, and an additional 63 new fellowships awarded. The total number of fellowships will increase prior to launch of the EOS satellites, thereby ensuring a pool of highly qualified Earth scientists to disseminate the data generated during the 15-year mission lifetime. Eventually, the program will fund up to 200 graduate students per year for the duration of the mission; of course, the availability of funds dictates the final number of scholarships.

Candidates must be admitted to or already enrolled in full-time Ph.D. programs at accredited U.S. universities or other institutions of higher education. Students may also apply in their senior year prior to receiving their baccalaureate degree, but must be enrolled in a Ph.D. program at a U.S. university at the time of award. Applications will be considered for research on climate and hydrologic systems, ecological systems and dynamics, biogeochemical dynamics, solid Earth processes, human interactions, data and information systems, and solar influences. Atmospheric chemistry and physics, ocean biology and physics, ecosystem dynamics, hydrology, cryospheric processes, geology, and geophysics are also acceptable areas of study, provided that the research topic is relevant to NASA's global change efforts—specifically, the Earth Observing System and Mission to Planet Earth.

Petitions for a Graduate Student Fellowship in Global Change Research entail a completed application form, copies of undergraduate and graduate transcripts (if applicable), a letter of reference from the academic advisor, and a titled five-page research proposal for those already enrolled in a program of study or a statement of research interest for those just entering graduate school. Instructions for preparing the research proposal and the ancillary forms can be acquired by sending written queries to:

NASA Global Change Fellowship Program
Code SE-44 (GC)
NASA Headquarters
Washington, D.C. 20546

Global Change Fellowship information packets are available each January, and must be completed by April 1 to be considered for the following academic year. Ten copies of the application form, proposal, transcripts, and letter of reference need to be forwarded as a package to the above address. Incomplete packages and/or those received after the April 1 deadline are not considered in the selection process.

Applications are reviewed on a competitive basis through a two-step process. The first step involves a mail review, which weans out deficient proposals by assessing the calibre of student, quality of research, and relevance to the NASA Global Change Research Program. Those applications that pass the initial screening are then evaluated by a panel composed of members of professional scientific societies, academic institutions, NASA Centers, and NASA Headquarters. Results of the competition are announced by June 30th, with the anticipated starting date of awarded fellowships September 1st. Students receiving stipends must not receive other Federal funding, including monies from other Federal fellowships, traineeships, or employment.

Competition for a Graduate Student Fellowship in Global Change Research is quite fierce. Over 1,000 applications have been submitted since program inception in 1990. To date, 159 fellowships have been awarded, with the chosen students representing 61 universities and 19 countries. Refer to Table 10 for a listing of the fellowship recipients spanning the 1990 to 1992 time frame; a grey screen highlights those students who have completed their graduate studies. U.S. citizens and resident aliens are given preference in the review process; however, this does not preclude foreign nationals who are pursuing their graduate studies in the U.S. from applying. No one shall be denied consideration or appointment on grounds of race, creed, color, national origin, age, or sex.

A student receiving support under the Global Change Fellowship Program does not incur any formal obligation to the Government of the United States; however, the objectives of this program will clearly be served best if the student is encouraged to actively pursue global change research after completion of graduate studies. By offering the opportunity to participate in this prestigious program, NASA hopes to attract the world's most outstanding scientists, both in the role of graduate fellows and faculty advisors. The ultimate goal is to increase the number of well-trained Earth scientists in the EOS era. ☆

Table 10. Global Change Fellowship Recipients—1990 to 1992

GCC	Fellow	Citizenship	Institution	Proposal Title
Biogeochemical Dynamics	Linnea M. Avallone	USA	Harvard University	High Pressure and Low Temperature Dynamics of Chlorine and Bromine Species
	Margaret G. Bac	USA	Stanford University	Molecular and Isotopic Characteristics of Oceanic Carbon: Imps for Global Var of Atmos and Oceanic C02
	David W. Bolgrien	USA	University of Wisconsin	Satellite Limnology: Use of Remote Sensing in the Assessment of Water Quality of Large Lakes
	Anne M. Braunschweig	USA	University of Minnesota	Modeling of Methane Production from Minnesota Peat Lands
	Margaret K.M. Brown	USA	University of Washington	Analysis of Methane Isotopic Composition Data
	Li Chen	China	University of Colorado	Study of Ozone Response to Solar UV Variation over 27 Days Using a 2D Chemical-Radiative-Dynamical Model
	James R. Christian	Canada	University of Hawaii	The Role of Bacterial Exoenzymes and Exopolysaccharides in Biogeochemical Cycling in the Upper Ocean
	Montgomery Cochran	USA	Yale University	Weathering, Plants, and the Geochemical Carbon Cycle
	Andrew E. Dessler	USA	Harvard University	Participation in Second NASA Airborne Arctic Stratospheric Experiment
	Mary-Lynn Dickson	Canada	Oregon State University	Nitrogen Dynamics in the Upper Ocean: The Role of the Pelagic Foodweb Structure
	Rachel Freifelder	USA	Stanford University	Biogeochemical and Ecosystem Effects of Grass Invasion and Fire in Hawaiian Seasonally Dry Forest
	Sara A. Garver	USA	University of California	SeaWiFS Ocean Color Inversion Method for the Study of Upper Ocean Ecosystem Dynamics
	Stephen K. Hamilton	USA	University of California	Regional-Scale Hydrological and Biogeochemical Processes in the Brazilian Gran Pantanal Wetlands
	Kevin G. Harrison	USA	Columbia University	The Effects of Changing Land Use on Organic C and N Storage in Mid-Lat N.American Soil and Rice Paddies
	Ann P. Kinzig	USA	University of California	Effects of Global Warming on Trace Greenhouse Gas Fluxes
	Raphael M. Kudela	USA	University of Southern California	Estimation of New Prod for a Coastal Upwelling Region Using Remotely Sensed SST and Pigment Concentrations
	Laura L. Landrum	USA	University of Washington	Modeling CO2 Uptake in the North Pacific
	Kristen J. Leckrone	USA	Indiana University	Development of a Tech for Rapid Determination of Stable Carbon Isotopic Composition of DOC in Seawater
	Steven A. Lloyd	USA	Harvard University	Key Radiative, Chemical, and Dynamical Processes Controlling Stratospheric Ozone Abundance
	Natalie M. Mahowald	USA	Massachusetts Institute of Technology	3-D Model of Trace Gas Transport and Chemistry Based on Observed Winds: Nitrous Oxide, Methane, and CFCs
	James J. Marti	USA	University of Minnesota	Role of Polar Stratospheric Clouds in Antarctic Ozone Depletion
	James H. Mather	USA	Penn State University	Measurement of Tropospheric OH Using a Laser-Induced Fluorescence Technique
	Ann M. Middlebrook	USA	University of Colorado	Heterogeneous Chemistry of Model Stratospheric Aerosol Films
	Michael J. Mills	USA	University of Colorado	Mid-Latitude Ozone Chemistry: Observations and Predictions of OClO
	Philip W. Mote	USA	University of Washington	Assessing the Stratospheric Water Vapor Using NCAR 3-D Model
	Antonio D. Nobre	Brazil	University of New Hampshire	Measuring and Modeling Biospheric Sources of Atmospheric N2O
	Simo O. Pehkonen	Finland	California Inst of Technology	The Speciation of Iron in Marine Atmospheres
	Lars L. Pierce	USA	University of Montana	Towards Global Sims of Terrestrial Biogeochemical Cycles: Evapotranspiration and Net Primary Production
	Beth M. Plotkin	USA	University of Washington	Modeling OH Field Using 14CO and CO Data
	Ajit Subramaniam	India	State University of New York	Role of Trichodesmium Blooms in Enhancing Primary Production in the Northwestern Indian Ocean
	Young Sunwoo	Korea	University of Iowa	Tropospheric Ozone and Long-Range Transport of Pollutants in the Pacific Rim
	Azadeh Tabazadeh	USA	University of California	A Proposal to Study the Contribution of Heterogeneous Chemical Processes to Global Change
	Tara Toolan	USA	Harvard University	Quantification of Biological Utilization of Dissolved Organic Matter
	Margaret S. Torn	USA	University of California	Environmental Controls over Methane Flux from Natural Ecosystems
	Alan R. Townsend	USA	Stanford University	Responses of Soil Organic Materials to Changes in Temperature
	Jennifer L. Young	USA	University of Washington	234Th as a Tracer of New Production in the Central Equatorial Pacific
	Shari A. Yvon	USA	University of Miami	The Cycling of SO2 in the Marine Atmosphere
	Renyi Zhang	China	Massachusetts Institute of Technology	Heterogeneous Reaction Mechanisms of Polar Ozone Depletion Involving Ice and Ice-Like Substrates

Table 10. Global Change Fellowship Recipients—1990 to 1992 (Continued)

GCC	Fellow	Citizenship	Institution	Proposal Title
Climate and Hydrologic Systems	Afshan Alam	India	University of Colorado	Thermodynamic Coupling Between the Atmosphere and Arctic Ocean
	Sybil M. Anderson	USA	University of California	Modeling and Analysis of Marine Sulfur Chemistry/Climate Feedback Mechanism
	Jian W. Bao	China	Penn State University	Four-Dimensional Data Assimilation Using the Adjoint Method
	Ana P. Barros	Portugal	University of Washington	The Role of the Alpine Cryosphere in Global Change Research
	Cynthia J. Beegle	USA	University of Washington	The Decadal Circulation of the Pacific Ocean as Elucidated by Chlorofluorocarbons
	Eric Breitenberger	USA	University of Alaska	Sea Ice and its Relationship with Atmospheric Circulation
	Sundar A. Christopher	India	S.Dakota School of Mines and Tech	Cloud Radiative Forcing in the Tropics: The Effects of Optical Property Retrievals and Scene Identification
	Shaoping Chu	China	Rice University	Atmosphere-Sea-Ice-Ocean Interactions and Climate Change
	Timothy M. Del Sole	USA	Harvard University	Numerical Studies of the Atmospheric Heat Flux Using a Two-Layer Model
	Charlotte A. DeMott	USA	Colorado State University	A Radar and Modeling Study of Oceanic and Continental Mesoscale Convective Systems
	A. Scott Denning	USA	Colorado State University	Investigation of Atmosphere-Biosphere Interactions Using a General Circulation Model with NOAA AVHRR Data
	Elfatih A.B. Eltahir	Sudan	Massachusetts Institute of Technology	Precipitation Recycling and Sensitivity of Regional Climate in the Amazon Basin
	Maria Cristina Forbes	Argentina	University of Miami	Low Frequency (Seasonal) Variability in the South Atlantic Using Geosat Altimetric Data
	Xiaogang Gao	China	University of Arizona	Parameterizing Land-Surface Hydrologic Processes up to the GCM Scale
	Alexander Gershunov	USA	University of California	Water Vapor Within and Beyond the Greenhouse
	Marguerite Gerstell	USA	California Inst of Technology	Investigate the Influence of Cloud Systems on the Runaway Greenhouse Effect
	Richard J. Gosnell	USA	University of Colorado	Sensitivity of Tropical Oceans to Fresh Water Flux and the Use of TRMM Data in Ocean Modeling
	John S. Greene	USA	University of Delaware	An Improved Climatology of Oceanic Precipitation
	Thomas J. Greenwald	USA	Colorado State University	Cloud Radiative Effects and Their Role in Global Climate
	Darren J. Hakeman	USA	Stanford University	Improvement of Global Rainfall Sampling Through Long-Range Detection of Lightning Sferics (TRMM)
	Jeffrey A. Hicke	USA	University of California	A Study of Surface Cloud Forcing
	Paul R. Houser	USA	University of Arizona	Soil Moisture Investigations
	Marilyn G. Hughes	USA	Rutgers University	The Use of Snow Cover as an Indicator of Anthropogenic Climate Change
	John D. Isham	USA	University of Massachusetts	An Electronically Steered Thinned Array Radiometer for Global Change Research
	Tara L. Jensen	USA	Colorado State University	Studies of the Relationship Between Marine Aerosols and Cloud Properties
	Catherine A. Jones	USA	Florida State University	Sea-Surface Stress Maps and SST
	Stephen A. Klein	USA	University of Washington	Clouds: Radiation and Large-Scale Dynamics
	John A. Knaff	USA	Colorado State University	Study of the Apparent Fundamental Relationship Between the Stratospheric QBO and Tropical Convection
	Praveen Kumar	India	University of Minnesota	Scale Invariance of Remotely Sensed Hydrologic Fluxes: Theoretical Dev and Role in GC Climate Research
	John M. Kwiatkowski	USA	Michigan Tech University	Applications of Polarimetric Radar in Coherent Imaging of Earth and Remote Sensing of Precipitation
	Chris W. Landsea	USA	Colorado State University	A Study of Interannual and Interdecadal Fluctuations of Hurricanes
	Dah-Syang Lin	Taiwan	Princeton University	Active Microwave Remote Sensing of Surface Soil Moisture and its Applications to Land-Atmospheric Modeling
	Brent M. Lofgren	USA	Princeton University	Assessing Potential Feedbacks Among Soil Moisture, Surface Albedo, and Climate
	Alison M. MacDonald	USA	Massachusetts Institute of Technology	A Global Inverse Solution to the Heat and Freshwater Fluxes of the World Ocean
	Nathan J. Mantua	USA	University of Washington	The Influence of Basic States on the Behavior of a Tropical Coupled Ocean-Atmosphere Model
	Wieslaw Maslowski	Poland	University of Alaska	3-D Numerical Modeling of the Marginal Ice Edge Zone of the Greenland Sea
	Cecile Mauritzen	Norway	Woods Hole Oceanographic Inst	Ocean Circulation in the Greenland and Norwegian Seas

Table 10. Global Change Fellowship Recipients—1990 to 1992 (Continued)

GCC	Fellow	Citizenship	Institution	Proposal Title
Climate and Hydrologic Systems (Continued)	Thomas L. Mote	USA	University of Nebraska	Spatial and Temporal Variations of Passive Microwave-Derived Surface Melt on the Greenland Ice Sheet
	Joanna E. Muench	USA	University of Washington	Generation and Propagation of 21-Day Waves during the 1982/83 El Niño
	Jon T. Nelson	USA	University of Washington	Transformation of Precursor Gases to Aerosol Particles and Growth into Cloud Droplets
	Joel R. Norris	USA	University of Washington	Role of Clouds in Perturbations of Climate System
	Vannaroth Nuth	USA	University of Texas	The Monitoring of Global Ice Sheet and Mean Sea Level Changes Using Satellite Altimetry
	Karen L. O'Brien	USA	Penn State University	The Impacts of Deforestation on the Climate of Chiapas, Mexico
	Andrew W. Paylor	USA	University of Massachusetts	Effects of Low Wind Speed and Rain Upon Radar Backscatter from the Ocean Surface
	Scott D. Peckham	USA	University of Colorado	Scaling and Multi-Scaling of Hydrologic Processes with the Aid of Remote Sensing
	Thomas Peterson	**USA**	**Colorado State University**	**An Observational Study of Surface Warming, Clouds, Water Vapor, and Radiative Effects**
	Andrew N. Pilant	USA	Michigan Tech University	The Effects of Snow Microstructure, Dielectric Properties, and Substrate Conditions on Snow Microwave Emission
	Robert M. Pincus	USA	University of Washington	An Investigation of Marine Stratocumulus Breakup Using Satellite Observations
	John N. Porter	USA	University of Hawaii	AVHRR-Derived Marine Aerosol Measurements: Validations and Improvements
	Russell J. Qualls	USA	Cornell University	Determining the Dependency of Sensible Heat Flux on Surface Temperature and Soil Moisture
	Eric P. Salathe	USA	Yale University	Upper Level Water Vapor and Atmospheric Radiation
	Brian J. Soden	USA	University of Chicago	Governing of Climate by Cloud-Radiative Forcing Feedbacks
	Jie Song	China	University of Delaware	Influence of Heterogeneous Land Surface on the Surface Energy Budget at GCM Scales
	Richard W. Turner	New Zealand	Iowa State University	The Effect of Changes in Soil-Moisture Level and Distr on Regional-Scale Circulations of the Midwestern U.S.
	Andrew M. Vogelmann	USA	Penn State University	Cirrus Cloud Radiative Modeling
	Richard G. Wagner	USA	University of Wisconsin	Atmosphere-Ocean Dynamics and Mechanisms of Climate Change in the Tropical Atlantic Sector
	John W. Weatherly	USA	University of Illinois	Study of Sea Ice and Salinity Anomalies in the Artic Ocean Using a Coupled Ice-Ocean Model
	Rodney J. Weber	Canada	University of Minnesota	New Particle Formation in the Marine Troposphere by Homogeneous Nucleation
	Wendell T. Welch	USA	University of Washington	Baroclinic Instability in Global Heat Transport
	Susan Wijffels	Australia	Woods Hole Oceanographic Institution	The Role of the Tropical Pacific in the Global Heat and Freshwater Balances
	Denise L. Worthen	USA	University of Washington	A Modeling Study of the Hydrology of the Arctic Ocean
	Randolph H. Wynne	USA	University of Wisconsin	Lakes as Indicators of Global Change
	Sandra E. Yuter	USA	University of Washington	Evolution of Vertical Structure of Tropical Precipitation
	Edward D. Zaron	USA	Oregon State University	An Investigation of the North Pacific
Data and Info Systems	Yongmao Chen	China	University of California	A Spatio-Temporal Data Model and High-Level Language
	James W. Hardin	**USA**	**Texas A&M University**	**Detectability of Global Change with Discrete Global Observing Systems**
	Ari Juels	USA	University of California	An Algorithmic Model for Massively Parallel Computers, with Sequoia 2000 as a Testbed
	Daniel J. Kraiman	USA	University of California	I/O Performance of Scientific Applications on Supercomputers
	Yong Qian	China	University of Maryland	Exploitation of the Potential Computing Capabilities of Climate Models on a Massively Parallel Computer
	Aya C. Soffer	Israel	University of Maryland	An Integrated Heterogeneous Multimedia Image Database
	Gerard K.C. Yeh	USA	Stanford University	A Low Power Pipeline Interleaved Image Signal Processor for Remote Sensing
SI	Eugene C. Cordero	USA	University of California	Solar Influences on the Dynamics of the Equatorial Middle Atmosphere
	Carter L. Grotbeck	USA	University of Arizona	Solar Aureole Instrumentation and Inversion Techniques for Aerosol Studies
	Theresa P. Hartsell	USA	University of Colorado	Multispectral Modeling of Observed Solar Time Series

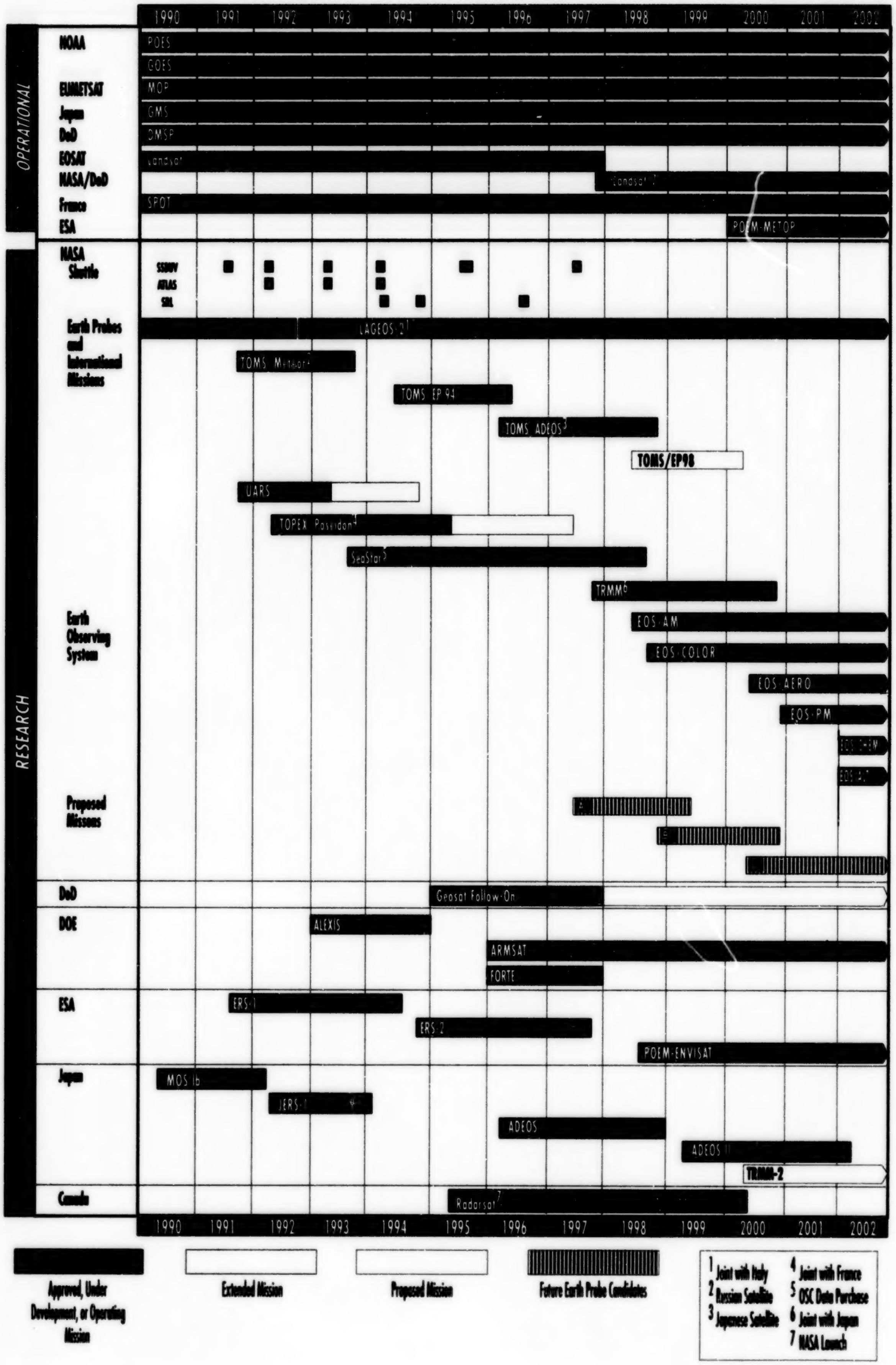
▨ Global Change Fellowship Graduate

Table 10. Global Change Fellowship Recipients—1990 to 1992 (Continued)

GCC	Fellow	Citizenship	Institution	Proposal Title
Ecological Systems and Dynamics	Susan L. Bassow	USA	Harvard University	Dynamic Interaction Between Forest and Atmosphere
	Tracy L. Benning	USA	University of Colorado	Retrospective Analysis of Productivity in Response to Climatic Variations
	Daniel G. Brown	**USA**	**Michigan State University**	**Stress, Disturbance, and Climatic Sensitivities Affecting the Pattern of Vegetation at Alpine Treeline**
	Virginia B. Brown	USA	Colorado State University	Testing Models of Plant Canopy Structure and Gas Exchange
	Lisa J. Carlson	USA	University of Washington	Modeling Forest Response to Climate Change: Lessons from the Past
	William M. Childress	USA	Texas A&M University	Cellular Automata: A Paradigm for Linking Large and Small-Scale Spatial Processes in Ecology
	Anne F. Cross	USA	Duke University	Biogeochemistry at the Desert Grassland-Desert Shrubland Boundary: A Case Study of Regional Desertification
	Mary B. Decker	USA	University of California	Ecology of High-Latitude Marine Birds in Relation to Variations in Oceanographic and Climatic Processes
	Douglas O. Fuller	USA	University of Maryland	Remote Sensing of Vegetation Phenology as an Indicator of Global Change
	Anne E. Hartley	USA	Duke University	An Arid Ecosystem Processes Model for Studying Desertification
	Sarah E. Hobbie	USA	University of California	Effects of Increased Temp on Tundra Plant Community Composition and the Consequences for Ecosystem Proc
	Mark E. Jakubauskas	USA	University of Kansas	Landscape-Scale Vegetation Dynamics
	Paul W. Leadley	USA	San Diego State University	Response of Arctic Vegetation to Global Change
	Michael A. Lefsky	USA	University of Virginia	Interfacing Remotely Sensed Data with Physiologically Based Vegetation Models
	Sandra S. Luque	Argentina	Rutgers University	Temporal Changes in Landscape Patterns/Conditions and Relation with Human Impact and Natural Disturbances
	Camille Parmesan	USA	University of Texas	Use of a Butterfly Species as a Bio-Indicator of Climate Change: Time-Series Analysis of Population Extinction Rates
	Christopher C. Spaur	USA	NC State University	Late Holocene Coastal Wetlands Evolution at Jarrett Bay, North Carolina
	Ricardo Villalba	Argentina	University of Colorado	Long-Term Forest Dynamics in Patagonia
	Alison M. Wallace	USA	State University of New York	Effects of Genetic and Environ Variation in Response to Increased CO2 on the Comp Ability of Lupinus Arboreus
	John F. Weishampel	USA	University of Virginia	Interfacing Remotely Sensed Data to Dynamic Forest Models
	Brian J. Wilsey	USA	Syracuse University	Plant Responses to Simulated Grazing and Elevated Atmospheric CO2: A Comparative Ecosystem Approach
	Charles G. Wray	USA	Yale University	A Phylogenetic and Paleoclimatic Analysis of Foraminiferal Evolution
HI	Lisa L. Gezon	USA	University of Michigan	Conservation in Madagascar: Satellite Images to Understand the Human Dimensions of Forest Degradation
	Andrew Sluyter	Canada	University of Texas	Holocene Environmental Change of the Southern Gulf of Mexico Tropical Lowland
Solid Earth Processes	Suzanne P. Anderson	USA	University of California	Effect of Flowpath, Runoff, and pCO2 on Chemical Weathering Rates in a Steep Deforested Catchment
	Alan F. Arbogast	USA	University of Kansas	Paleoenvironments and Desertification of a Large Sand Sheet in the Central Great Plains
	Gino Casassa	Chile	Ohio State University	Use of Satellite Imagery to Investigate Causes for Ongoing Changes in West Antarctica
	Darryl E. Granger	USA	University of California	Measurement of Physical and Chemical Weathering Associated with Mountain Ranges
	Geoffrey A. Haddad	USA	Rice University	Quarternary Intermediate Water C02 Levels Inferred from Sea-Floor Aragonite Preservation Patterns
	Rick E. Holasek	USA	University of Hawaii	Remote-Sensing Analysis of Co-Ignimbrite Eruption Plumes Detected by Weather Satellites
	Keith A. Horton	USA	University of Hawaii	Temporal Change on Volcanoes, and the Interaction between Volcanoes and the Earth System
	Frex Sigmundsson	**Iceland**	**University of Colorado**	**Active Isostasy in Iceland**
	Andrea Szilagyi	**Hungary**	**Purdue University**	**Analysis and Modeling of Relationships Between Salinity and Spectral Reflectance of Soils**
	Thor Thodarson	Iceland	University of Hawaii	Basaltic Fissure Eruptions and their Impact on the Earth's Atmosphere
	Gregory E. Tucker	USA	Penn State University	Modeling the Interaction of Climate, Tectonics, and Topography on a Regional Scale

▨ Global Change Fellowship Graduate

Figure 10. U.S. and International Partner Earth-Observing Missions



MISSION ELEMENTS

This section provides specifics on the space-based elements that make up the International Earth Observing System. Refer to Figure 10 on the facing page for a schedule of ongoing and planned U.S. and international partner Earth-observing missions. This timeline is not confined to IEOS; rather, it provides a fairly comprehensive listing of relevant Earth remote-sensing satellites, many of which do not receive attention in the following pages. The timeline purposefully encompasses missions beyond the scope of IEOS to show how IEOS fits into the larger scheme of Earth observations satellites. Given the volatile nature of platform configurations and scheduling, this chart should be considered more of a planning document, accurate through February 1993.

The following mission descriptions correspond to Table 7 in the International Cooperation section. Each space-based element makes unique contributions to overall IEOS objectives, so the order of discussion should not connote a ranking or prioritization of any kind:

- Earth Observing System (EOS) missions
- Advanced Earth Observing System (ADEOS) missions
- Tropical Rainfall Measuring Mission (TRMM)
- Polar-Orbit Earth Observation Mission (POEM) satellites
- Polar-Orbiting Operational Environmental Satellite (POES) series.

For the sake of brevity, instrument acronyms are not defined herein (see the Acronym List on page 142).

EOS MISSIONS

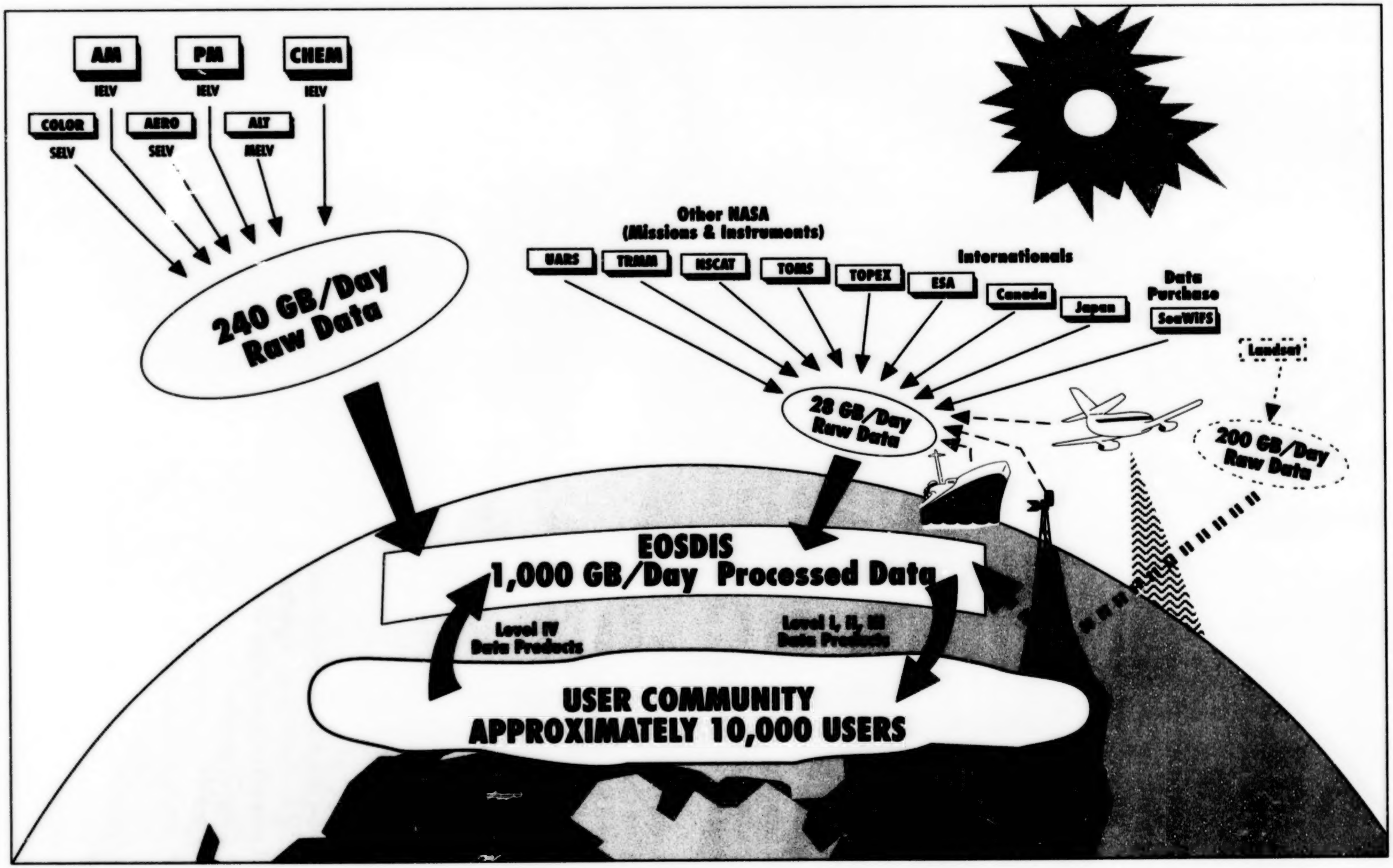
EOS remains a long-term program to provide continuous observations of global climate change. Repeating flights of the principal EOS spacecraft on 5-year centers will ensure adequate coverage for at least 15 years; however, payloads of the follow-on EOS spacecraft could change, depending on the evolution of scientific understanding and the development of technology.

The EOS Program includes nine intermediate-sized spacecraft—three of which will be morning sun-synchronous (EOS-AM series), three afternoon sun-synchronous (EOS-PM series), and three sun-synchronous polar (EOS-CHEM series). The EOS-AM, -PM,and -CHEM spacecraft will be placed into 98.2° inclined, 705-km, 16-day, 233-orbit repeat cycles, with the EOS-AM series having a 10:30 a.m. descending nodal crossing, the EOS-PM series a 1:30 p.m. ascending nodal crossing, and the EOS-CHEM series a 3:30 p.m. descending nodal crossing. The three smaller spacecraft that comprise the EOS-ALT series will be placed into sun-synchronous polar orbits, and five very small spacecraft will have 57° inclined orbits (EOS-AERO series).

The spacecraft in each of the three primary series will be functionally identical, with only minor changes expected in the instrument complements. EOS-AM1 is the only exception. The rescoping deliberations resulted in the initiation of a common spacecraft bus design to reduce total program cost (see the EOS Science Objectives and EOS Chronology sections for more detail). It was decided that adhering to the current EOS-AM1 development schedule provided the greatest assurance of meeting the June 1998 launch readiness date. As such, the EOS-PM1 instrument complement will be the first to be integrated onto the common spacecraft bus, which will be used on all subsequent missions (except for EOS-AERO, -COLOR, and -ALT). The EOS-AERO spacecraft will be provided via an international partner. EOS-COLOR involves a one-time acquisition of ocean primary productivity observations via a data purchase, as will be done for the Sea-Viewing Wide Field Sensor (SeaWiFS) which is scheduled for launch onboard SeaStar in late 1993. Figure 11 illustrates the rescoped program-level architecture, and offers the data-handling requirements expected for EOS era remote-sensing satellites.

As stated earlier in the EOS Science Objectives section, the presence of MODIS on both the EOS-AM and -PM spacecraft proves central to the program. MODIS has important simultaneity requirements with other instruments on both EOS-AM and -PM; furthermore, flying MODIS on each of these spacecraft eliminates the need for complicated formation flying. MODIS redundancy yields complete global ocean color measurements by avoiding sun-glint over the northern oceans and the lack of illumination over the southern oceans. By taking further advantage of their complementary ascending and descending orbits, MODIS provides cloud observations needed to interpret CERES radiation budget measurements, which also are collected by both EOS-AM and -PM platforms. In addition,

Figure 11. EOS Rescoped Program-Level Architecture


AM
IELV
PM
IELV
CHEM
IELV
COLOR
SELV
AERO
SELV
ALT
MELV
240 GB/Day
Raw Data
Other NASA
(Missions & Instruments)
UARS
TRMM
NSCAT
TOMS
TOPEX
Internationals
ESA
Canada
Japan
Data
Purchase
SeaWIFS
Landsat
28 GB/Day
Raw Data
200 GB/Day
Raw Data
EOSDIS
1,000 GB/Day Processed Data
Level IV
Data Products
Level I, II, III
Data Products
USER COMMUNITY
APPROXIMATELY 10,000 USERS

SAGE III is flown on both EOS-AERO and -CHEM to provide observations of aerosols and temperature from two different orbits (i.e., 57° inclination and polar, respectively).

The instruments assigned to EOS-CHEM, -ALT, -AERO, and -COLOR were carefully selected to provide overlap and supplemental data in conjunction with the EOS-AM and -PM flights. They also provide continuity for certain types of measurements. The EOS-COLOR mission is based on a SeaWiFS-type instrument design. EOS-COLOR data will be placed into EOSDIS for archive and distribution, providing researchers with observations on ocean biogeochemistry, its role in the global carbon cycle, and its role in the feedback of physical phenomena such as heat storage in the upper ocean and cloud albedo. Since this mission will not involve a series of launches, refer to its writeup in the EOS Instruments section for further information. The continuity of ocean color data beyond 2000 is ensured by having two or more MODIS instruments in orbit on EOS-AM and -PM spacecraft from 2001 until the end of the EOS observational lifetime (refer back to Figure 5 for a listing of EOS instruments on-orbit during the first 12 years of the EOS mission).

The descriptions of the EOS satellite series that follow emphasize the first platform in the series, since requirements may change as the program evolves. Detailed descriptions of all instruments that remain as part of the rescoped EOS Program can be found in the EOS Instruments section.

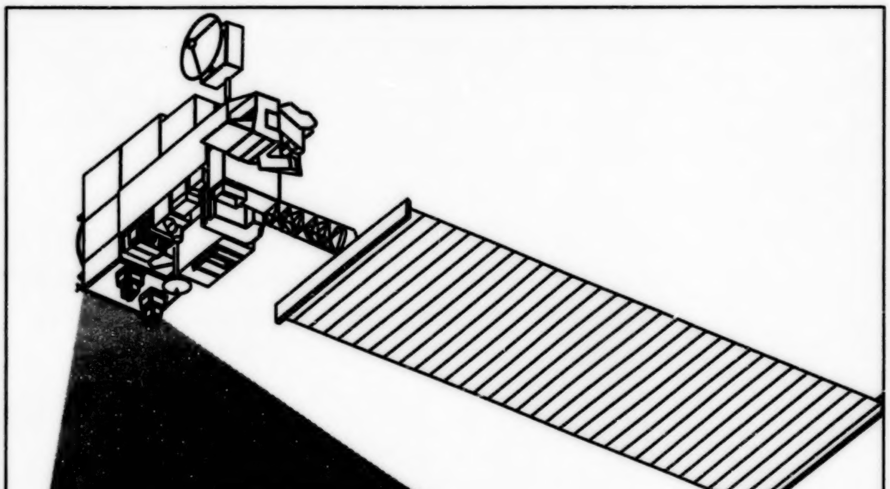


Figure 12. The EOS-AM1 Satellite and Payload

EOS-AM Series

Planned for launch in June 1998, the EOS-AM1 flight includes five instruments to be placed into a polar, sun-synchronous, 705-km orbit by an IELV. The launch will take place from the U.S. Air Force Western Space and Missile Center (WSMC). The payload consists of ASTER, CERES (dual scanner), MISR, MODIS, and MOPITT. As stated above, the EOS-AM1 spacecraft will have a unique design.

EOS-AM1 will have an equatorial crossing time of 10:30 a.m., when daily cloud cover is typically at a minimum over land such that surface features can be more easily observed. The instrument complement is intended to obtain information about the physical and radiative properties of clouds (ASTER, CERES, MISR, MODIS); air-land and air-sea exchanges of energy, carbon, and water (ASTER, MISR, MODIS); vertical profiles of important greenhouse gases (MOPITT); and volcanology (ASTER, MISR, MODIS). CERES, MISR, and MODIS are provided by the U.S.; MOPITT is provided by Canada; and ASTER is provided by Japan. The EOS-AM1 spacecraft design (see Figure 12) will support an instrument mass of 1,120 kg, an average power for spacecraft and instruments of 3 kW (3.5 kW peak), and an average data rate of 16 Mbps (150 Mbps peak). Onboard solid-state recorders will collect at least one orbit worth of data for playback through TDRSS, even though a playback on each orbit is planned.

The mission plan includes three AM flights—EOS-AM1 to be launched in June 1998, EOS-AM2 in June 2003, and EOS-AM3 in June 2008. Since the EOS-AM1 spacecraft is unique, changes in the follow-on flights have already been scheduled. MODIS, MISR, and CERES remain onboard EOS-AM2, though the latter instrument will carry only a single scanner. Negotiations are still underway to accommodate MOPITT on EOS-AM2. ASTER will be dropped in favor of TES and EOSP, both of which provide tropospheric aerosol and chemistry data. With the possible exception of MOPITT, EOS-AM3 is expected to bear the same payload as EOS-AM2.

The EOS-AM1 spacecraft will also include the Direct Access System (DAS), which is composed of the Direct Playback (DP) subsystem, the Direct Broadcast (DB) subsystem, and possibly the Direct Downlink (DDL) subsystem. While it is planned that all EOS data will be recorded and played back via TDRSS, DAS will provide a backup option for direct transmittal of onboard data to ground receiving stations via an X-band transmitter (DP subsystem) should the satellite lose its TDRSS link. DAS will also support transmission to ground stations of qualified EOS users around the world who require direct data reception. These users fall into three categories:

- EOS team participants and interdisciplinary scientists who require real-time data to conduct or validate field observations, to plan aircraft campaigns, or to observe rapidly changing conditions in the field
- International meteorological and environmental agencies that require real-time measurements of the atmosphere, storm and flood status, water temperature, and vegetation stress
- International partners who require receipt of data from their high-volume EOS instruments at their own analysis centers for engineering quality checks and scientific studies.

The DB subsystem will broadcast MODIS data at 11 Mbps. At this rate, properly equipped ground stations can receive, process, and display the swath data as the EOS observatory passes within range. These ground stations will be similar to current Landsat facilities.

EOS-PM Series

Current plans call for EOS-PM1 to be launched in December 2000. This satellite series will include six instruments to be placed into a polar, sun-synchronous, 705-km orbit. The EOS-PM instrument complements will be integrated onto the common satellite bus described earlier, with the spacecraft boosted into orbit by an IELV launched from WSMC. The payload consists of AIRS, AMSU, CERES, MHS, MIMR, and MODIS. The EOS-PM series spacecraft will have an afternoon crossing time to enhance collection of meteorological data by the atmospheric sounders onboard. The instrument complement is designed to provide information on cloud formation, precipitation, and radiative properties (AIRS, AMSU, CERES, MHS, MODIS); air-sea fluxes of energy, carbon, and moisture (AIRS, AMSU, MHS, MIMR, MODIS); and sea-ice extent (MIMR, MODIS). AIRS, AMSU, CERES, and MODIS are provided by the U.S.; MHS is provided by EUMETSAT; and MIMR is provided by ESA. The EOS-PM series spacecraft will include the DB and DP capabilities of DAS (see the EOS-AM Series writeup), with the DB subsystem transmitting all instrument data save that from CERES.

Currently, the plan is for all EOS-PM satellites to be identical, except that CERES will consist of two scanners on EOS-PM1 and a single scanner on the follow-on flights. EOS-PM2 is scheduled for launch in December 2005, followed by EOS-PM3 in December 2010. The EOS-PM spacecraft design will support an instrument mass of 1,100 kg, average power for the instruments of 1,200 W (1,630 W peak), and an average data rate of 7.7 Mbps (12.5 Mbps peak).

EOS-AERO Series

At present, SAGE III is the only instrument assigned to the EOS-AERO series, whose first flight is scheduled for launch in 2000 on an SELV. Current plans call for the use of an internationally contributed spacecraft to be placed into a 57° inclined, 705-km (or slightly lower) orbit to optimize collection of occultation data in the equatorial latitudes. This series involves five spacecraft launched on 3-year centers to provide the required 15-year coverage. The follow-on flights are scheduled for 2003, 2006, 2009, and 2012. SAGE III is capable of making long-term trend measurements of aerosols, ozone, water vapor, and clouds from the middle troposphere through the stratosphere—important parameters for radiative and atmospheric chemistry models.

The instrument mass is expected to be 40 kg, with an average instrument power of 15 W (60 W peak) and an average data rate of 26 kbps (100 kbps peak).

EOS-ALT Series

Current plans call for EOS-ALT1 to be launched into a sun-synchronous polar orbit by an MELV in 2002. Subsequent launches are slated for 2007 and 2012. The EOS-ALT payload was dramatically reconfigured during the rescoping exercise, with the U.S. ALT and GGI instruments eliminated to reduce total program cost; NASA must now rely on substantial international participation. The instrument complement that resulted consists of GLAS, TMR, DORIS, and SSALT—the former two are U.S. instruments and the latter two are provided by France. In addition to precise orbit tracking (DORIS, TMR) and altimeter calibration and orbit determination (SSALT), the EOS-ALT series will provide measurements of sea ice and glacier surface topography, cloud heights, and aerosol vertical structure (GLAS).

The instrument mass is expected to be 300 kg, with an average instrument power of 290 W (320 W peak) and an average data rate of 215 kbps.

EOS-CHEM Series

The EOS-CHEM series will employ the same common satellite bus that will be used for the EOS-AM2/3 and -PM flights. As with the EOS-ALT series, the rescoping of the EOS Program had a significant impact on this mission. STIKSCAT and TES were removed from this platform, with the former to fly as the NSCAT follow-on (NSCAT II) on ADEOS II and the latter shifted to EOS-AM2 and -AM3. The instrument complement now consists of ACRIM, HIRDLS, MLS, SAGE III, SOLSTICE II, and an as yet to be determined Japanese contribution. This payload will be launched on IELVs into 705-km, sun-synchronous orbits. The first launch is slated for 2002, with the follow-ons to be launched in 2007 and 2012. EOS-CHEM instruments will provide measurements of solar energy flux (ACRIM); solar ultraviolet radiation (SOLSTICE II); atmospheric aerosols, ozone, and water vapor (SAGE III); atmospheric trace gases (HIRDLS); and ozone, based on chlorine monoxide, bromine oxide, and water vapor (MLS). The EOS-CHEM spacecraft will include the DB and DP capabilities of DAS (see the EOS-AM Series writeup); the DB subsystem will service only the HIRDLS and MLS instruments.

Instrument mass is expected to be 940 kg, with an average instrument power of 980 W (1,080 W peak) and an average data rate of 1.1 Mbps (1.2 Mbps peak).

ADEOS MISSIONS

Japan plans to launch the polar-orbiting ADEOS mission in February 1996. The objectives of ADEOS include Earth, atmospheric, and oceanographic remote sensing. ADEOS will be launched into a sun-synchronous, 98.6° inclination orbit with an ~800-km altitude, and an equatorial crossing time of 10:30 a.m. The satellite will have a ground-track repeat cycle of 41 days, providing global OCTS coverage every 3 days and daily coverage (sampled) for AVNIR. ADEOS is designed for a 3-year mission lifetime; an ADEOS follow-on is expected to be launched in 1999. ADEOS will fly the following instruments:

- **AVNIR**—Five visible/near-infrared bands (0.420 to 0.890 μm); 16- or 8-m resolution; 80-km swath; ±40° across-track pointing; stereo capability. Observation of sunlight reflected by Earth's surface. Developed by NASDA.
- **ILAS**—Infrared occultation device; one visible band at 0.753-0.781 μm, and two infrared bands at 6.21-11.77 and 5.99-6.78 μm (16-cm^{-1} resolution); 2 x 10 km IFOV; observations from 10-60 km, approximately 4-km vertical resolution expected; retrieval of stratospheric ozone and related species at high latitudes. Provided by Japan's Environmental Agency.
- **IMG**—Nadir-looking Fourier transform infrared spectrometer; range 3.3-14.0 μm, with a spectral resolution of 0.1 cm^{-1}; ~10 km^2 foot print; vertical resolution ~2-6 km depending on species ; observation of carbon dioxide, methane, and other greenhouse gases. Provided by MITI.
- **NSCAT**—14 GHz (Ku band) operation; resolution of 25 km; two 600-km swaths. Used for retrieval of wind speed and direction over the oceans. Provided by NASA.
- **OCTS**—Six visible bands centered on 0.412, 0.443, 0.490, 0.520, 0.565, and 0.670 μm, 20-nm bandwidth, S/N = 450-500; two near-infrared bands centered on 0.765 and 0.865 μm, 40-nm bandwidth, S/N = 450-500; four thermal infrared bands centered on 3.7, 8.5, 11.0, and 12.0 μm, 330- to 1,000-nm bandwidth, NEDT 0.15 to 0.20K at 300K; 700-m resolution; 1,400-km swath; ±20° along-track tilting; measurement of ocean color and sea-surface temperature. Developed by NASDA.
- **POLDER**—Views ±55° (cross- and along-track); 5-km^2 nadir footprint; eight bands in the visible and near-infrared, 0.443 to 0.910 μm with 10- to 20-nm

bandwidth; all-polarization measurements in three of the eight bands. Provided by CNES.

- **RIS**—0.5-m diameter corner-cube retro-reflector to derive column density of ozone and trace species from laser absorption measurements. A ground station in the Kanto area will transmit and receive laser pulses in the wavelength region from 0.4 to 14 µm. Provided by Japan's Environmental Agency.
- **TOMS**—Six wavelength bands in the region from 0.309-0.360 µm, with 1-nm bandpass; IFOV 50 km at nadir; cross-track scan 105° (35 3° steps); retrieves daily global ozone. Provided by NASA.

ADEOS II will be the main Japanese contribution to IEOS, since ADEOS falls more within the framework of MTPE Phase I than the EOS era. The conceptual design of ADEOS II is still underway; however, one proposal calls for dividing ADEOS II into two separate missions, with the first satellite to be launched in 1999. Both satellites would have orbital specifications similar to the ADEOS mission. AMSR and GLI would be the core global imaging sensors for ADEOS IIa, complemented by IMG-2 and the U.S. NSCAT II (next-generation instruments of those described above):

- **AMSR**—Multifrequency microwave radiometer to observe atmospheric and oceanic water vapor profiles, such as precipitation, water vapor distribution, cloud water, sea surface temperature, sea ice, and sea surface wind speed; employs six frequencies in the 6 to 90 GHz range, with vertical and horizontal polarization, to secure a temperature resolution of 0.2 to 1K at 1K (goal) radiometric accuracy; instrument design employs a 2-m antenna aperture, and is based on MSR (MOS-1) heritage.
- **GLI**—Imaging spectrometer for global monitoring of biological and physical processes and stratospheric ozone in the spectral range from the ultraviolet to the thermal infrared; 20 bands, with a bandwidth of 10-20 nm and a signal-to-noise ratio of less than 1,000; 1,800-km swath; instantaneous field-of-view of less than 1 km; instrument design based on VTIR (MOS-1) and OCTS (ADEOS) heritage.

The entire ADEOS IIb payload—consequently its launch date—has yet to be determined. Strong candidates for ADEOS IIb include a next-generation version of AVNIR (ADEOS heritage) and a radar to ensure continuity with SAR data derived from JERS-1.

TRMM

Conducted in cooperation with Japan, TRMM is a joint NASA/NASDA mission with the sole objective of measuring precipitation—undoubtedly the most difficult atmospheric variable to quantify, and the crucial driver of the hydrologic cycle and atmospheric dynamics. TRMM will measure diurnal variation of precipitation in the tropics from a low-inclination orbit using a variety of sensors. The goal of this mission is to obtain a minimum of 3 years of significant climatological observations of rainfall in the tropics; in tandem with cloud models, TRMM observations will provide accurate estimates of vertical distributions of latent heating in the atmosphere.

NASA will provide the TRMM spacecraft, a microwave imager, a visible/infrared imager, a lightning imaging sensor, a radiation budget instrument, and instrument integration. Japan is providing a precipitation radar and the H-II rocket to launch the satellite in August 1997. TRMM will have a 350-km, 35° orbit. The payload consists of the following instruments:

- **CERES**—See EOS Instruments section for a detailed description.
- **LIS**—See EOS Instruments section for a detailed description.
- **PR**—An electronically scanning radar operating at 13.8 GHz; 4.3 km^2 instantaneous field-of-view at nadir; 220-km swath. Provided by NASDA.
- **TMI**—A five-channel passive microwave imager making measurements from 10 to 91 GHz. Provided by NASA.
- **VIRS**—A five-channel imaging radiometer (0.63, 1.6, 3.75, 10.7, and 12.0 µm) with nominal 2-km resolution at nadir and 1,500-km swath; similar in design to NOAA's AVHRR-3. Provided by NASA.

A TRMM follow-on (TRMM-2) is being considered for launch in 2000. The payload complement for this proposed mission is currently being discussed by the international Earth science community.

POEM SATELLITES

The POEM satellites will make comprehensive research and operational observations of the Earth. POEM will be implemented as two spacecraft series—one for environmental monitoring and atmospheric chemistry (ENVISAT), and one for operational meteorological and climate monitoring (METOP). POEM-METOP will contribute significantly to operational meteorology by providing a long-term venue for the operational package in the morning orbit. Both satellites will use the *Columbus* polar platform, and both will be equipped to work with the European Data Relay Satellite System (DRSS). A major effort is being made on ground segment development, based on experience gained from ERS-1 and -2. The flight and ground segment is being developed through the participation of ESA, EUMETSAT, and the European Community (EC); cooperation with the U.S. and Japan is also being pursued through exchange of instrumentation and data. In the outyears of the POEM Program, advanced instrumentation will be integrated onto the platforms, with candidates including a lidar, a multifrequency SAR, and a high-resolution thermal infrared radiometer.

POEM Environmental Satellite

POEM-ENVISAT has the dual objectives of continuing ERS measurements and contributing to environmental studies in land surface properties, atmospheric chemistry, aerosol distribution, and marine biology. The instrument package will consist of five ESA-funded instruments and four instruments provided by individual ESA member states. The ESA facility instruments include ASAR, GOMOS, MERIS, MIPAS, and RA-2, which includes a microwave sounder. The following national contributions are also included on the POEM-ENVISAT manifest: AATSR, PRAREE, SCARAB, and SCIAMACHY. The first POEM-ENVISAT launch is scheduled for mid-1998, with the launch of a second planned for 2003. Brief instrument descriptions follow, with the facility instruments preceding the AO contributions:

- **ASAR**—A high-resolution, all-weather imaging SAR that will provide information on ocean waves, surface topography, land surface properties, snow and ice extent, and sea ice extent and motion; operates in two modes (imaging mode and wave mode). The imaging mode takes measurements in the C-band (5.3 GHz), with a bandwidth of 15.55 MHz, 30-m spatial resolution, and 100-km swath width; the wave mode operates at 5.3 GHz and has a spatial resolution of 30 m, generating 5 x 5 km images of the surface at regular intervals to determine ocean wave features.
- **GOMOS**—Monitors global ozone, enhancing knowledge of ozone depletion and its impact on the greenhouse effect; provides stable reference data on global ozone, plus observations of H_2O, NO_2, NO_3, ClO, BrO, OClO, temperature (O_2), and aerosols through the use of two bore-sighted telescopes, each with its own grating spectrometer [spectrometer A covers the spectral ranges of 0.25-0.45 µm and 0.425-0.65 µm (0.6-nm resolution); spectrometer B covers the ranges of 0.758-0.772 µm and 0.926-0.943 µm (0.07-nm resolution)]; limb-viewing mode operates over a vertical range of approximately 20-100 km, and has a vertical resolution of ~2 km; synergistic with MIPAS and SCIAMACHY.
- **MERIS**—Measures ocean color and biological components of the ocean, lending insight into the ocean's contribution to the carbon cycle; provides high spectral resolution (5-20 nm) measurements in up to 15 selectable channels from 0.405 to 1.030 µm (channel selection programmable in orbit); channels are composites of solar spectrum measured over adjacent Charged Coupled Device (CCD) detectors; ~600 CCD detectors available in the spectral dimension, and up to about one-third of these can be sampled; 1,500-km swath width; spatial resolution programmable to 250 x 250 m and 1,000 x 1,000 m (±20° along-track tilt); synergistic with RA-2, ASCAT, and AATSR.
- **MIPAS**—Limb sounder to measure the composition, dynamics, and radiation balance of the middle and upper atmosphere (i.e., atmospheric chemistry, ozone mapping, and monitoring of the greenhouse effect/global warming); height range of 8-100 km, and 3-km vertical/30-km horizontal resolution; very high spectral resolution (0.025 nm), rapid-scanning capability permits retrieval of temperature, water vapor, ozone, and numerous trace gases (e.g., CH_4, CCl_4, HNO_3); sensitivity ranges from 4.15 to 14.6 µm in four spectral bands; synergistic with GOMOS and SCIAMACHY for complementary measurements (i.e., three-dimensional temperature field, aerosol loading, polar stratospheric cloud detection, and atmospheric chemistry).
- **RA-2**—Provides significant wave height and sea level determination, ocean circulation (dynamics), ice sheet topography, and land mapping data; adaptive pulse-limited radar altimeter possesses a transmit center frequency of 13.8 GHz, and an optional 3.2 GHz transmit

frequency to measure and correct for ionospheric delays; an adaptive range window resolution (with bandwidth up to 330 MHz) is used for automatic gain control; synergistic with ASCAT, MERIS, and AATSR; ensures continuity of ERS-1/2 data products.

- **AATSR**—Provides high-precision sea surface temperature retrieval and land-surface bidirectional measurements for ocean dynamics and radiation interaction studies; imaging radiometer with 10 channels (bandwidth listed parenthetically) [0.470 µm (20 nm), 0.550 µm (20 nm), 0.670 µm (20 nm), 0.870 µm (20 nm), 1.240 µm (20 nm), 1.610 µm (60 nm), 3.750 µm (400 nm), 4.0 µm (TBD), 10.85 µm (1,000 nm), 12.0 µm (1,000 nm)]; signal-to-noise ratio equals 20 for the visible/near-infrared channels, 800 at 270K for the 12- and 10.85-µm channels, and 227 at 270K for the 3.75-µm channel; 500-km swath width; 500-m field-of-view (FOV) at nadir for channels up to 1.6 µm and a 1-km FOV for channels beyond 1.6 µm; two viewing angles (nadir and 47° forward from nadir); synergistic with RA-2, ASCAT, and MERIS; provides continuity with ERS-1/2 data products.
- **PRAREE**—Provides high-precision orbitography, geodesy, plate tectonics, and ocean topography data; refines satellite position to within millimeters, studies plate motion, and monitors seismic deformation through the use of a two-way, three-frequency (X, S, and UHF bands) tracking system, complemented by laser corrections; operates with at least 20 ground stations; complements RA-2.
- **SCARAB**—Provides global measurements of the radiation budget; 4-channel (0.2-4, 0.2-50, 0.5-0.7, and 10.5-12.5 µm) mechanical cross-track scanner that includes broadband, total, and shortwave channels for radiation budget determinations and narrow-band infrared window and visible channels for improved cloud detection. All four channels will have a 60-km spatial resolution and a field-of-view of 100°.
- **SCIAMACHY**—Measures the total concentration and vertical distribution of atmospheric trace gas species (i.e., H_2O, O_3, CH_4, N_2O, NO, NO_2, NO_3, ClO, SO_2, BrO, OClO, HCHO, CO, CO_2), temperature (O_2 and CO_2 bands), and aerosols in the troposphere and stratosphere; two identical optical paths capable of viewing in limb-scanning (including occultation) or nadir modes, using array detectors and grating spectrometers in the spectral ranges of 0.240-0.295 µm (0.11 nm), 0.290-0.405 µm (0.12 nm), 0.400-0.700 µm (0.15 nm), 0.650-1.050 µm (0.20 nm), 0.940-1.350 µm (0.20 nm), 1.980-2.020 µm (0.08 nm), and 2.250-2.390 µm (0.09 nm); signal-to-noise ratio can be up to 5,000 in the ultraviolet/visible and 500 in the infrared; possesses a vertical resolution of 1 km from 20-100 km in limb-sounding mode (3-km retrievals expected); scans ±40° in nadir-viewing mode; 0.25 x 25 km field-of-view at nadir; synergistic with MIPAS and GOMOS.

ASAR, RA-2, MERIS, and AATSR establish a unique observation and measurement complement for the biophysical characterization of oceans and coastal zones (>70% of the Earth's surface), thus giving an important key to climate and global environmental monitoring.

MIPAS, GOMOS, and SCIAMACHY comprehensively monitor greenhouse gases, thereby studying global warming, ozone depletion, and climatic influence. Together with SCARAB, they provide a tool to characterize both the lower and upper atmosphere, in view of its dynamics, radiative transfer, interactions, and the weather.

RA-2 and PRAREE must be flown on the same platform.

POEM Meteorological Operational Satellite

This collaborative venture between ESA, NOAA, and EUMETSAT has the current objective of operational meteorology and climate monitoring, and a future objective of operational climatology. A preparatory program for METOP was approved at the November 1992 ESA Ministerial Conference. The complete payload will be determined in 1994, when final program approval and funding is expected. The core operational meteorology payload consists of six instruments: AMSU-A1/2, AVHRR-3, DCS (ARGOS+), HIRS-3, IASI, and MHS. The operational meteorological package also includes MCP, S&R, and SEM. In addition, the following instruments have been proposed for climatological monitoring: ASCAT, AATSR, GOMI, MIMR, and SCARAB. Original plans called for certain NOAA operational instruments (i.e., AVHRR-3, AMSU-A1/2, and HIRS-3) to be replaced by their next-generation successors. At present, NOAA does not believe that it can meet ESA and EUMETSAT's ambitious development and integration requirements in time for a 2000 launch; instead, NOAA plans to contribute the versions that fly on the POES series, with subsequent METOP flights carrying the advanced IRTS, MTS, and VIRSR instruments in their place. Plans call for a second POEM-METOP satellite to be launched in 2005. The following subsections address the discrete elements that make up the current POEM-METOP payload configuration, and anticipated enhancements to be integrated onto follow-on flights.

Operational Meteorological Package

The Operational Meteorological Package will replace NOAA's morning satellite series. This instrument package will make operational weather observations on a regular basis. This package is synergistic with all other instruments on the POEM-METOP satellite, and will facilitate calibration of other instruments subject to atmospheric interference (e.g., AATSR). Brief descriptions of the instruments that comprise the operational meteorological package follow:

- **AMSU-A1/2**—15 channels (23-90 GHz) to measure temperature profiles from ground level to 45 km, with 45-km nadir resolution (14-bit resolution); scan line time of 8 sec includes full aperture calibration.
- **AVHRR-3**—Six spectral channels (five full-time) at 0.58-0.68 µm, 0.72-1.0 µm, 1.58-1.64 µm (sun-side readout)/3.55-3.93 µm (dark-side readout), 10.3-11.3 µm, and 11.5-12.5 µm, with an image resolution of 1-4 km (effective 11-bit resolution); infrared calibration capability, but no visible calibration.
- **DCS (ARGOS+)**—Relays messages from data collection platforms at 401.0 and 136.77 MHz; receives platform and buoy transmissions on 401.65 MHz; monitors over 4,000 platforms worldwide; outputs data via VHF link and stores them on tape.
- **HIRS-3**—20 channels at 0.2-15 µm to cover the surface to the troposphere, with 21-km nadir resolution (12-bit resolution), a scan line time of 6.4 sec, and full aperture calibration.
- **IASI**—Provides atmospheric temperature and humidity profiles with high vertical resolution and accuracy, and continuous monitoring of global radiation, dynamics, and energy flux; high-resolution spectrometer with a spectral band of 3.4-15.5 µm and a spectral resolution of 0.25 cm^{-1}; 1-km vertical resolution; 1K temperature accuracy.
- **MCP**—Provides direct data handling and broadcast of operational instrument data streams to ground stations.
- **MHS**—Measures precipitation and water vapor profiles with two channels at 89 and 150 GHz, and three at 183.31 GHz (1, 3, and 7 GHz bandwidths); scan line time will be 8 and 3 sec, respectively; possesses full aperture calibration and 15-km nadir resolution (14-bit resolution); provided by EUMETSAT.
- **S&R**—Receives beacon signals at 121.5, 243, and 406.05 MHz (-154 dBm signal detection level); transmits in real-time at 1,544.5 MHz to ground stations around the world.
- **SEM**—Monitors particles and fields to measure and predict solar events.

The next-generation meteorological operational instruments slated for flight on POEM-METOP2 and subsequent spacecraft include:

- **IRTS**—Scanning radiometer to provide global atmospheric temperature profiles, atmospheric water content, cloud properties, and Earth radiation budget data; 20 channels covering the ground to the troposphere, from 0.2 to 15 µm; 2,250-km swath width, with 21-km (12-bit) resolution at nadir and full aperture calibration; scan line time of 8 sec includes calibration; instrument design based on HIRS-3 heritage.
- **MTS**—Employs 21 channels covering ground level to 73 km, including upper atmosphere soundings; provides full aperture calibration and 45-km nadir resolution (14-bit resolution); scan line time of 8 sec includes calibration.
- **VIRSR**—Provides global monitoring of clouds, sea surface temperature, vegetation, and ice; 2,200-km swath width, with 1.1-km (12-bit) resolution at nadir; employs seven full-time spectral channels (0.605-0.625, 0.860-0.880, 1.580-1.640, 3.620-3.830, 8.400-8.700, 10.30-11.30, and 11.50-12.50 µm), plus onboard visible and infrared calibration; scan mode reversed from traditional imagers; signal-to-noise ratio on all infrared channels will be 0.1° and 300K.

Climatological Monitoring Package

The following facility instruments have been proposed for climatological monitoring, with eventual transition to operational climatology:

- **AATSR**—See description in POEM-ENVISAT subsection.
- **ASCAT**—Measures ocean surface wind speed and direction, and ocean circulation and dynamics; accurate to 2 m/sec (direction to 20°); provides 25 x 25 km resolution; has a double swath (2 x 500 km) capability; operates at 14 GHz; synergistic with RA-2, MERIS, and AATSR for biophysical characterization of the ocean, ocean dynamics, and energy exchange; ensures continuity with ERS-1/2 data products.
- **GOMI**—A grating spectrometer that will retrieve global ozone distributions from both solar radiation backscatter and differential optical absorption spectroscopy; operates over four spectral channels (0.240-0.295, 0.290-0.405, 0.400-0.605, 0.590-0.790 μm) at a moderately high spectral resolution of 0.2-0.4 nm; pixel size on the ground of 40 x 1.7 km, and spatial resolution between 40 x 40 km and 40 x 320 km.
- **MIMR**—See EOS Instruments section for a detailed description.
- **SCARAB**—See description in POEM-ENVISAT subsection.

POES SERIES

NOAA's primary agency directive is to provide daily global data for operational forecasts and warnings, with very high reliability. NOAA normally has two POES in operation at the same time, one in a morning and one in an afternoon orbit; each is replaced upon failure or significant degradation of one of its primary sensors or subsystems. Over 120 countries depend on the data from the POES direct broadcast.

The present POES system will continue through 2000. The core instruments for the POES missions are AVHRR-3 and HIRS-3—an imager and an infrared sounder, respectively. POES spacecraft are also equipped with the ARGOS data collection system, S&R, and SEM. POES satellites in afternoon orbit (i.e., NOAA-11/I/K/M/N') also carry SBUV. The stratospheric and microwave pair of sounders now in use (i.e., SSU and MSU) are being upgraded, beginning with NOAA-K; NOAA-K through -N' will employ the AMSU-A1/2 and AMSU-B sounder pair.

The U.S. and Europe have agreed in principle that Europe will take over responsibility for the morning satellite of the POES global coverage mission in the 2000 time frame. Planning for this cooperative program includes flight of the NOAA/EUMETSAT operational meteorological payload aboard the POEM-METOP series. Also, EUMETSAT will establish a high-latitude European ground station to read out data from both the European and U.S. (NOAA) satellites. Full exchange of data, in a timely manner consistent with operational objectives, will be conducted between NOAA and EUMETSAT. Current plans are for these two agencies to provide morning (EUMETSAT) and afternoon (NOAA) polar satellite global coverage, with each using the same basic instrument complements. The U.S. will provide the AMSU-A1/2, AVHRR-3, HIRS-3, and SEM instruments to be flown on POEM-METOP1; EUMETSAT will provide the AMSU-B instruments for NOAA's POES series; France will provide the ARGOS systems for both the NOAA and EUMETSAT missions; and Canada and France will jointly provide the S&R systems for both NOAA and European polar missions. Each meteorological agency may add other instruments suitable to its particular orbit time and needs.

Direct broadcast of POES data will continue, with European polar satellites also providing direct data broadcast services. In addition, data from potential operational instruments on the EOS satellites will be accessed and disseminated by NOAA.

The establishment and use of a high-latitude European ground station under the cooperative NOAA-EUMETSAT agreement will eliminate blind orbits in coverage by polar-orbiting meteorological satellites. This enhanced ground network will eliminate orbits wherein the satellite fails to pass within line-of-sight for data transmission to its ground station. Both NOAA and EUMETSAT's meteorological payloads will be able to downlink a full orbit's worth of data at full resolution each orbit. As such, there will no longer be a need for low-resolution GAC data to conserve POES onboard data storage capacity. All POES data in the cooperative program will be full-resolution Local Area Coverage (LAC) data. The low-resolution, analog Automatic Picture Transmission (APT) as well as the Direct Sounding Broadcast (DSB) of the current NOAA system will be replaced with Low-Resolution Picture Transmission (LRPT) broadcasts. The High-Resolution Picture Transmission (HRPT) data rate will be changed from 667 kbps to 3.5 Mbps, and the HRPT frequency will be changed to 1,704.5 MHz.

NOAA-K/L/M/N/N′ Instruments

- **ARGOS**—Relays messages from data collection platforms at 401.0 and 136.77 MHz; receives platform and buoy transmissions on 401.65 MHz; monitors over 4,000 platforms worldwide; outputs data via VHF link and stores them on tape.
- **AMSU-A1/2**—15 channels (23-90 GHz) to measure temperature profiles from ground level to 45 km, with 45-km nadir resolution (14-bit resolution); scan line time of 8 sec includes full aperture calibration.
- **AVHRR-3**—Six spectral channels (five full-time) at 0.58-0.68 μm, 0.72-1.0 μm, 1.58-1.64 μm (sun-side readout)/3.55-3.93 μm (dark-side readout), 10.3-11.3 μm, and 11.5-12.5 μm, with an image resolution of 1-4 km (effective 11-bit resolution); infrared calibration capability, but no visible calibration.
- **AMSU-B**—Measures precipitation and water vapor profiles with two channels at 89 and 157 GHz, and three at 183.31 GHz (1, 3, and 7 GHz bandwidths); scan line time is 8/3 sec, respectively; 15-km nadir resolution (14-bit resolution) and full aperture calibration capability.
- **HIRS-3**—20 channels at 0.2-15 μm to cover the ground to the troposphere, with 21-km nadir resolution (12-bit resolution), a scan line time of 6.4 sec, and full aperture calibration.
- **SBUV-2** (NOAA-K/M/N′ only)—12 spectral channels to measure from 0.252-0.322 μm, with a 1-nm bandpass; 256-sec spectral scan; 11.33° x 11.33° instantaneous field-of-view; 14-bit resolution; diffuser plate calibration accomplished with an onboard spectral reflectance/transmittance measurement system; operates only on the day side of the orbit, and performs spectral calibration on the night side.
- **S&R**—Receives beacon signals at 121.5, 243, and 406.05 MHz (-154 dBm signal detection level); transmits in real-time at 1,544.5 MHz to ground stations around the world.
- **SEM**—Monitors particles and fields to measure and predict solar events. ☆

EOS Instruments

ACRIM
AIRS/AMSU/MHS
ASTER
CERES
DORIS/SSALT/TMR
EOS-COLOR
EOSP
GLAS
HIRDLS
LIS
MIMR
MISR
MLS
MODIS
MOPITT
NSCAT II
SAGE III
SOLSTICE II
TES

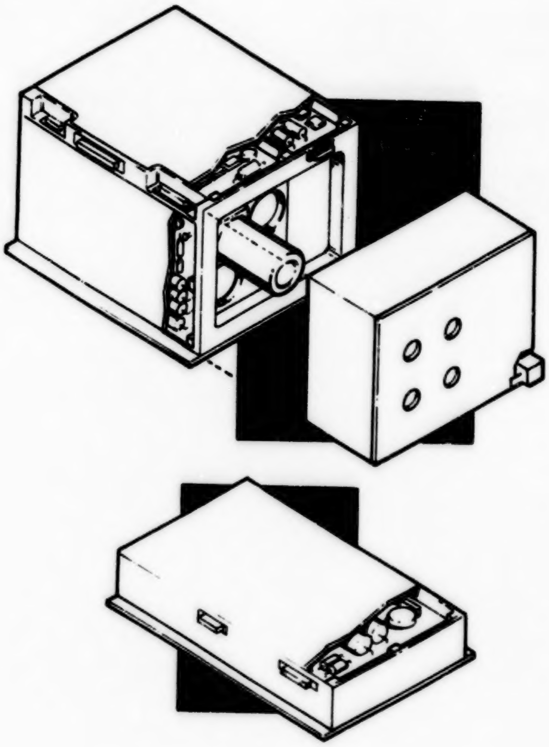
56 [illegible]

PRECEDING PAGE BLANK NOT FILMED

ACRIM

ACTIVE CAVITY RADIOMETER

IRRADIANCE MONITOR



THREE TOTAL IRRADIANCE DETECTORS: ONE TO MONITOR SOLAR IRRADIANCE, TWO TO CALIBRATE OPTICAL DEGRADATION OF THE FIRST

HERITAGE: ACRIM II (UARS)

MONITORS THE VARIABILITY OF TOTAL SOLAR IRRADIANCE

SOLAR IRRADIANCE UNCERTAINTY OF 0.1%;
LONG-TERM PRECISION OF 5 PPM PER YEAR

SAMPLING INTERVAL ~2 MINUTES

SENSOR ASSEMBLY MOUNTED ON TWO-AXIS TRACKER
TO OBSERVE SOLAR DISK DURING EACH ORBIT

The ACRIM experiment will sustain the NASA long-term solar luminosity database. The primary objective of ACRIM is to monitor the variability of total solar irradiance with state-of-the-art accuracy and precision, thereby extending the high-precision database compiled by NASA since 1980. Other ACRIM experiments have been included as part of the Earth radiation budget "principal thrust" in the National Climate Program. An overlap strategy has been pursued to maintain the continuous observation of solar irradiance with ACRIM and other space-based solar output monitoring instruments. Successful completion of the overlap strategy for ACRIM over the lifetime of the EOS mission will provide the last half of a NASA/ACRIM solar luminosity database 3 decades in length, with better than 50 ppm precision, including uncertainties caused by sensor degradation.

The ACRIM instrument contains three independent active cavity radiometer (ACR) solar-monitoring sensors and a sun-position sensor. One of the ACRs monitors the solar irradiance on a full-time basis, and the other two are used to calibrate optical degradation of the first. The ACRs are state-of-the-art pyrheliometers capable of defining the radiation scale with only a 0.1 percent uncertainty. The sun-position sensor is used in the science data stream to correct ACRIM results for off-sun pointing. The ACR pyrheliometer consists of two right circular conical cavity detectors that are thermally connected to a heat sink. The cavity interiors are coated with a specular black paint. The primary cavity is irradiated through a precisely machined and accurately measured primary aperture. The primary cavity detector is maintained at a slightly higher (1°C) temperature than the heat sink at all times. The secondary cavity drifts with the sensor heatsink, automatically subtracting its effects from the measurements. The basic principle is that the heating effect of irradiant solar flux on a detector is compared with that of electrical power dissipated in a heating element in intimate thermal contact with the same detector structure. Knowledge of the effective absorptance of the detector for the irradiant flux, the area of detector illumination, and the electrical heating power make possible the accurate and highly precise measurements of irradiant solar flux.

Selected for Flight on EOS-CHEM Series

ACRIM data products will consist of the average total solar irradiance at one Astronomical Unit, in units of watts per square meter, for each ACRIM shutter-open cycle. Results will be corrected for variations in satellite-sun distance and the relativistic effect of the platform's orbital velocity toward and away from the sun. Measurements will be made continuously during daylight passes, with integrated results at approximately 2-minute intervals. Daily mean results will be compiled and added to the database for use in climate and solar physics investigations. ACRIM data products will provide measurements of the total (bolometric) solar irradiance above the atmosphere, with absolute accuracy of 0.1 percent and long-term precision of 0.0005 percent per year. ☆

Key ACRIM Facts:
- In-house JPL development
- Currently in Phase B

For Further Information:
Wilson, R.C. and H.S. Hudson, The Sun's Luminosity over a Complete Solar Cycle, *Nature*, 351, 42-45, May 2, 1991.

ACRIM Parameters

Measurement Approach
Three active cavity radiometers monitor total solar irradiance to 99.9% accuracy

Swath: n/a (looks at sun)
Spatial resolution: n/a (looks at sun)

Accommodation Issues
Mass: 39 kg (excluding tracking platform)
Duty cycle: 100% (daylight only)
Power: 35 W (average), 40 W (peak)
Data rate: 1 kbps
Thermal control by: Heater, central thermal bus, radiator

Thermal operating range: 10-30°C
FOV: ±2.5°
Instrument IFOV: n/a
Pointing requirements (platform+instrument, 3σ):
  Control: 360 arcsec/axis
  Knowledge: 180 arcsec/axis
  Stability: 360 arcsec/axis
  Jitter: 360 arcsec/axis
Physical size: 38 x 14 x 18 cm (sensor assembly);
  13 x 15 x 25 cm (instrument electronics)

Requires pointing platform to be provided by spacecraft

Principal Investigator—Richard C. Willson

Richard C. Willson holds a doctoral degree in Atmospheric Sciences from the University of California–Los Angeles, and B.S. and M.S. degrees in Physics from the University of Colorado. He is a senior member of the technical staff and Supervisor of the Solar Irradiance Monitoring Group, Atmospheric and Cometary Sciences Section, Earth and Space Sciences Division, at the Jet Propulsion Laboratory (JPL). His career, which began at JPL in 1963, has involved primarily the development of state-of-the-art ACR pyrheliometry for use in solar total irradiance observations on balloon, sounding rocket, Space Shuttle, and satellite platforms. He has been the Principal Investigator for the Solar Maximum Mission ACRIM I, Space Shuttle Spacelab I, Atmospheric Laboratory for Applications and Science (ATLAS) ACRIMs, and Upper Atmosphere Research Satellite (UARS) ACRIM II experiments.

Co-Investigator

Hugh S. Hudson, University of Hawaii

AIRS, AMSU, and MHS

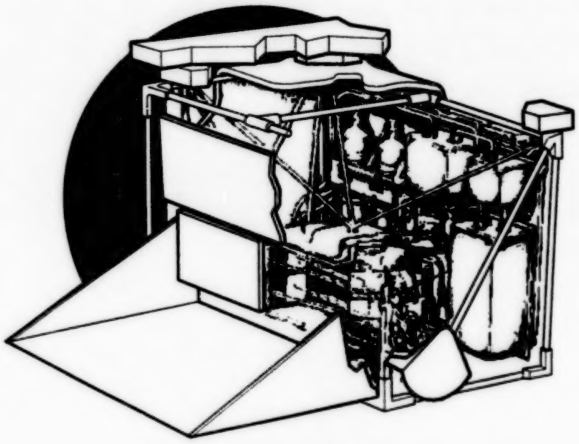
ATMOSPHERIC INFRARED SOUNDER, ADVANCED MICROWAVE SOUNDING UNIT, AND MICROWAVE HUMIDITY SOUNDER

AIRS

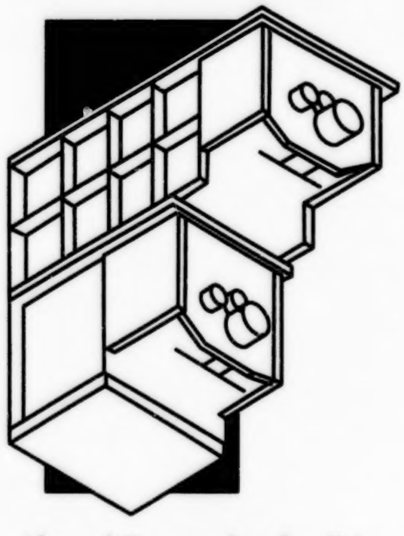
ATMOSPHERIC INFRARED SOUNDER

HERITAGE: HIRS 2, HIS

MEASURES THE EARTH'S OUTGOING RADIATION BETWEEN 0.4 TO 1.7 AND 3.4 TO 15.4 μM



Atmospheric Infrared Sounder



Advanced Microwave Sounding Unit

AMSU

MICROWAVE RADIOMETER

HERITAGE: MSU

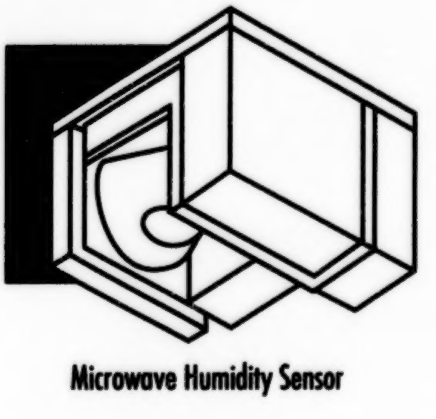
PROVIDES ATMOSPHERIC TEMPERATURE MEASUREMENTS FROM THE SURFACE UP TO 40 KM

MHS

MICROWAVE RADIOMETER

HERITAGE: MSU

PROVIDES ATMOSPHERIC WATER VAPOR PROFILE MEASUREMENTS



Microwave Humidity Sensor

Selected for Flight on EOS-PM Series

AIRS has been selected by NASA to fly on the EOS-PM1 satellite. The same platform will also carry two operational microwave sounders: NOAA's AMSU and EUMETSAT's MHS. AIRS is designed to meet the NOAA requirement of a high-resolution infrared (IR) sounder to fly on future operational weather satellites. AIRS, AMSU, and MHS measurements will be analyzed jointly to filter out the effects of clouds from the IR data in order to derive clear-column air temperature profiles and surface temperatures with high vertical resolution and accuracy. Together, these instruments constitute the advanced operational sounding system, relative to the High-Resolution Infrared Sounder/Microwave Sounding Unit (HIRS/MSU) system that currently operates on NOAA satellites.

The data retrieved from the AIRS/AMSU/MHS instrument complement will improve global modeling efforts, numerical weather prediction, study of the global energy and water cycles, detection of the effects of greenhouse gases, investigation of atmosphere-surface interactions, and monitoring of climate variations and trends. These objectives will be met through improvements in the accuracy of several weather and climate parameters, including atmospheric temperature and water vapor, land and ocean surface temperature, cloud distribution and spectral properties, and outgoing longwave radiation. Simultaneous observations of the atmosphere and clouds from AIRS will allow characterization of the spectral properties of clouds for enhanced understanding of their role in modulating the greenhouse effect, and the increased resolution and number of infrared sounding channels (an increase of two orders of magnitude beyond current operational sounders) will improve the accuracy of weather forecasting.

AIRS, AMSU, and MHS together constitute a single facility instrument program, so AIRS products are often the result of joint operations. Standard and research data products for the complement are delineated below:

- **Standard Products**
  - –For the atmosphere, AIRS/AMSU will provide a temperature profile, humidity profile, total precipitable water, fractional cloud cover, cloud top height, and cloud top temperature.
  - –For the land, AIRS/AMSU will provide skin surface temperature, plus day and night land surface temperature difference. AIRS will provide outgoing day/night longwave surface flux.
  - –For the ocean, AIRS/AMSU will provide skin surface temperature. AIRS will provide outgoing day/night longwave surface flux.
- **Research Products**
  - –For the atmosphere, AIRS/AMSU/MHS will provide a precipitation estimate, and tropopause and stratopause height. AIRS will provide outgoing longwave spectral radiation and cloud optical thickness. AMSU will provide cloud thermodynamic phase (ice/water) and cloud water content.
  - –For the land, AIRS/AMSU will provide surface spectral emissivity, surface albedo, and net shortwave flux.
  - –For the ocean, AIRS will provide net shortwave flux. AMSU will provide sea-ice cover (old/new) and surface (scalar) wind speed.

Standard products are distinguished from research products in that the latter will require post-launch verification.

AIRS

AIRS is a high-resolution sounder covering the spectral range between 0.4 and 15.4 μm, measuring simultaneously in over 2,300 spectral channels. The spectral resolution ($\lambda/\Delta\lambda$) is 1,200. The high spectral resolution enables the separation of the contribution of unwanted spectral emissions and, in particular, provides spectrally clean "super windows," which are ideal for surface observations. All channels will be downlinked on a routine operational basis.

Temperature profiles will be derived in the presence of multiple cloud layers without requiring any field-of-view to be completely clear. Humidity profiles will be derived from channels in the 6.3-μm water vapor band and the 11-μm windows, which are sensitive to water vapor continuum. Determination of the surface temperature and surface spectral emissivity is essential for obtaining low-level water vapor distribution.

Land skin surface temperature and the corresponding IR emissivity are determined simultaneously with the retrieval of the atmospheric temperature and water profiles. Shortwave window channels are used to derive the surface temperature and corresponding spectral emissivity, and to account for reflected solar radiation. Once the surface temperature is determined, the longwave surface emissivity for the 11-μm region can be determined, then used to retrieve the water distribution near the surface.

Cloud-top heights and effective cloud amount are determined based on the calculated atmospheric temperature, humidity, and surface temperature, combined with the calculated clear-column radiance and measured radiance. The spectral dependence of the opacity of the clouds will distinguish various cloud types (including cirrus clouds). Ozone retrieval is performed simultaneously with the other parameters using the 9.6-μm ozone band.

AIRS visible and near-IR channels between 0.4 and 1.0 μms will be used primarily to discriminate between low-level clouds and different terrain and surface covers, including snow and ice. In addition, the visible channels will allow the determination of cloud, land, and ocean surface parameters simultaneous with atmospheric corrections. Current implementation calls for four channels. One broadband channel from 0.4 to 1.0 μm will be used for the estimation of reflected shortwave radiation (i.e., albedo). Other channels will be used for surface properties such as ice and snow amount and vegetation index.

AMSU and MHS

AMSU is designed primarily to obtain profiles of stratospheric temperature and to provide a cloud-filtering capability for tropospheric observations; MHS is designed to obtain profiles of atmospheric humidity and to detect precipitation under clouds with 15-km (nadir) resolution. AMSU and MHS have a total of 20 channels: 15 are assigned to AMSU, each having a 3.3° beamwidth, and five are assigned to MHS, each having a 1.1° beamwidth. Channels 3 to 14 on AMSU are situated on the low-frequency side of the oxygen resonance band (50-60 GHz) and are used for temperature sounding. Successive channels in this band are situated at frequencies with increasing opacity, therefore responding to radiation from increasing altitudes. Channel 1 [located on the first (weak) water vapor resonance line] is used to obtain estimates of total column water vapor in the atmosphere. Channel 2 (at 31 GHz) is used to indicate the presence of rain.

Channel 15 on AMSU and channel 16 on MHS are both at 89 GHz, and are also used to indicate precipitation (i.e., at 89 GHz ice more strongly scatters radiation than it absorbs or emits). Channels 17 to 20 are located on the wings of the strongly opaque water vapor resonance line at 183.3 GHz. Again, successive channels in this group have decreasing opacity; therefore, they correspond to humidities at decreasing altitudes. Channels 17 to 20, along with inputs from channel 16 and channels 1 and 2, together with the temperature profile from AIRS/AMSU/MHS, are used to obtain profiles of atmospheric humidity (i.e., water vapor). ☆

AIRS Parameters

Measurement Approach
High spectral resolution, multispectral IR sounder
Operates with AMSU for all-weather capability
1K temperature retrieval accuracy
0.05 emissivity accuracy
Array grating spectrometer (3.74 to 15.4 μm), with a spectral resolution of 1200 ($\lambda/\Delta\lambda$)

Swath: 1,650 km
Spatial resolution: 13.5 km horizontal at nadir, 1 km vertical

Accommodation Issues
Mass: 140 kg
Duty cycle: 100%
Power: 224 W
Data rate: 1.42 Mbps
Thermal control by: Redundant 60K Stirling cycle coolers, heater, mini thermal bus, two-stage radiator
Thermal operating range: 20-25°C
FOV: ±49.5° cross-track
Instrument IFOV: 1.1° circular
Pointing requirements (platform+instrument, 3σ):

Control:	900 arcsec
Knowledge:	900 arcsec
Stability:	360/60 sec
Jitter:	TBD
Physical size:	116.5 x 80 x 95.3 cm (stowed); 116.5 x 158.7 x 95.3 cm (deployed)

Key AIRS Facts:
- Possible transition to NOAA-P/Q series
- Phase C/D start March 1991
- Prime Contractor: LORAL
- Responsible Center: JPL

Key AMSU Facts:
- Onboard NOAA-K/L/M and scheduled for NOAA-O/P/Q
- Phase C/D start December 1992
- Prime Contractor: Aerojet General Corporation
- Responsible Center: GSFC

Key MHS Facts:
- Onboard NOAA-K/L/M and scheduled for NOAA-O/P/Q
- Phase C/D start expected June 1994
- Phase B Contractors: Matra Marconi and British Aerospace
- EUMETSAT provides the instrument

For Further Information:
AIRS Science Team, The Atmospheric Infrared Sounder (AIRS) Science and Measurement Requirements, JPL Document #D6665.

AMSU Parameters

Measurement Approach
Passive microwave radiometer that measures atmospheric temperature

Swath: 1,650 km
Spatial resolution: 40 km horizontal at nadir

Accommodation Issues
Mass: 100 kg
Duty cycle: 100%
Power: 125 W
Data rate: 3.2 kbps

Thermal control by: Heater, central thermal bus, radiator
Thermal operating range: 0-20°C
FOV: ±49.5°
Instrument IFOV: 3.3°
Pointing requirements (platform+instrument, 3σ):
  Control: 720 arcsec
  Knowledge: 360 arcsec
  Stability: 360 arcsec/sec
  Jitter: 360 arcsec/sec
Physical size: 65.5 x 29.9 x 59.2 cm (A1);
54.6 x 64.9 x 69.7 cm (A2)

MHS Parameters

Measurement Approach
Passive microwave radiometer for humidity profiling, consisting of five channels: 1 at 89 GHz, 1 at 166 GHz, and 3 at 183.3 GHz

Swath: 1,650 km
Spatial resolution: 13.5 km horizontal at nadir

Accommodation Issues
Mass: 66 kg
Duty cycle: 100%
Power: 85 W (average), 190 W (peak)

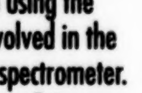
Data rate: 4.2 kbps
Thermal control by: Radiator
Thermal operating range: 0-40°C
FOV: ±49.5 cross-track from nadir (+90 to -49.5° for calibration)
Instrument IFOV: 1.1°
Pointing requirements (platform+instrument, 3σ):
  Control: 3,600 arcsec
  Knowledge: 360 arcsec
  Stability: 74 arcsec/sec
  Jitter: TBD
Physical size: 77.4 x 99 x 56 cm

Team Leader—Moustafa Chahine

Moustafa Chahine was awarded a Ph.D. in Fluid Physics from the University of California at Berkeley in 1960. He is Chief Scientist at the Jet Propulsion Laboratory (JPL), where he has been affiliated for nearly 30 years. From 1978 to 1984, he was Manager of the Division of Earth and Space Sciences at JPL; as such, he was responsible for establishing the Division and managing the diverse activities of its 400 researchers. For 20 years, Dr. Chahine has been directly involved in remote-sensing theory and experiments. His resume reflects roles as Principal Investigator, designer and developer, and analyst in remote sensing experiments. He developed the Physical Relaxation Method for retrieving atmospheric profiles from radiance observations. Subsequently, he formulated a multispectral approach using infrared and microwave data for remote sensing in the presence of clouds. These data analysis techniques were successfully applied in 1980 to produce the first global distribution of the Earth surface temperature using the HIRS/MSU sounders data. Dr. Chahine was integrally involved in the design study of AMTS, the precursor to the current AIRS spectrometer. Dr. Chahine served as a member of the NASA Earth System Sciences Committee (ESSC), which developed the program leading to EOS, and currently is Chairman of the Science Steering Group of a closely related effort, the World Meteorological Organization's Global Energy and Water Cycle Experiment (GEWEX). Dr. Chahine is a Fellow of the American Physical Society and the British Meteorological Society. In 1969, he was awarded the NASA Medal for Exceptional Scientific Achievements and, in 1984, the NASA Outstanding Leadership Medal.

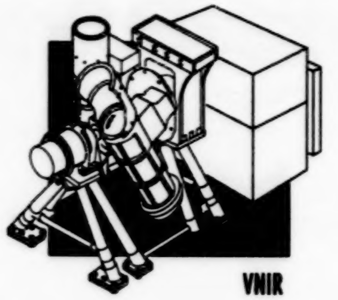
Team Members

Hartmut H. Aumann, Jet Propulsion Laboratory
Alan I. Chedin, Centre National d'Etudes Spatiales
Henry E. Fleming, NOAA/National Environmental Satellite, Data, and Information Service
Catherine Gautier, University of California–Santa Barbara
John F. Le Marshall, Bureau of Meteorology Research Centre
Larry M. McMillin, NOAA/National Environmental Satellite, Data, and Information Service
Ralph A. Petersen, NOAA/National Weather Service
Henry E. Revercomb, University of Wisconsin
Rolando Rizzi, European Centre for Medium-Range Weather
Philip Rosenkranz, Massachusetts Institute of Technology
William L. Smith, University of Wisconsin
David H. Staelin, Massachusetts Institute of Technology
L. Larrabee Strow, University of Maryland
Joel Susskind, Goddard Space Flight Center

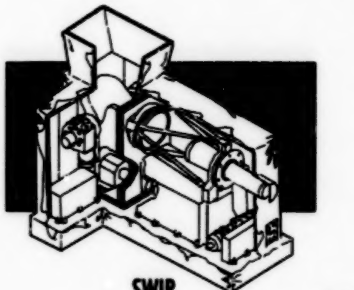


ASTER

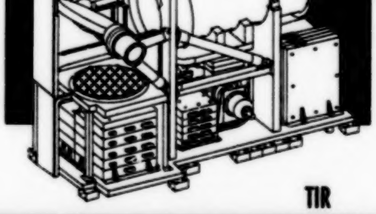
ADVANCED SPACEBORNE THERMAL EMISSION AND REFLECTION RADIOMETER



VNIR



SWIR



TIR

IMAGING RADIOMETER

HERITAGE: MESSR, OPS, LANDSAT, AND SPOT

PROVIDES HIGH SPATIAL RESOLUTION IMAGES OF THE LAND SURFACE, WATER, ICE, AND CLOUDS

SAME-ORBIT STEREO CAPABILITY

14 MULTISPECTRAL BANDS FROM VISIBLE THROUGH THERMAL INFRARED

ASTER—formerly known as the Intermediate Thermal Infrared Radiometer (ITIR)—is a facility instrument provided for the EOS-AM1 platform by the Japanese Ministry of International Trade and Industry (MITI). ASTER will operate in three visible and near-infrared (VNIR) channels between 0.5 and 0.9 μm, with 15-m resolution; six shortwave infrared (SWIR) channels between 1.6 and 2.5 μm, with 30-m resolution; and five thermal infrared (TIR) channels between 8 and 12 μm, with 90-m resolution. The instrument will acquire data over a 60-km swath whose center is pointable cross-track ±8.5° in the SWIR and TIR, with the VNIR pointable out to ±24°. An additional telescope (aft pointing) covers the wavelength range of Channel 3. By combining these data with those for Channel 3, stereo views can be created, with a base-to-height ratio of 0.6. ASTER's pointing capabilities will be such that any point on the globe will be accessible at least once every 16 days in all 14 bands and once every 5 days in the three VNIR channels.

ASTER data products will exploit combinations of VNIR, SWIR, and TIR for cloud studies, surface mapping, soil and geologic studies, volcano monitoring, and surface temperature, emissivity, and reflectivity determination. VNIR and SWIR bands will be used for investigation of land use patterns and vegetation, VNIR and TIR combinations for the study of coral reefs and glaciers, and VNIR for digital elevation models (DEMs). TIR channels will be used for study of evapotranspiration, and land and ocean temperature. The stereoscopic capability will yield local surface DEMs and allow observations of local topography, cloud structure, volcanic plumes, and glacial changes.

ASTER will provide high spatial resolution (15- to 90-m) multispectral images of the Earth's surface and clouds in order to better understand the physical processes that affect climate change. While the Moderate-Resolution Imaging Spectroradiometer (MODIS) and Multi-Angle Imaging Spectro-Radiometer (MISR) will monitor many of the same variables globally and on a daily basis, ASTER will provide data at a scale that can be directly related to detailed physical processes. These data will bridge the gap between field observations and data acquired by MODIS and MISR, and between process models and climate and/or forecast models. ASTER data will also be used for long-term monitoring of local and regional changes on the Earth surface, which either lead to or are in response to global climate change (e.g., land use, deforestation, desertification, lake and playa water level changes, and other changes in vegetation communities, glacial movement, and volcanic processes).

Clouds are one of the most important variables in the global climate system. With its high spatial resolution, broad spectral coverage, and stereo capability, ASTER will provide essential measurements of cloud amount, type, spatial distribution, morphology, and radiative properties. These data will help validate the cloud monitoring of MODIS and MISR by providing subpixel-level information.

ASTER will provide surface radiative (brightness) temperature, and the multispectral TIR data can be used to derive surface kinetic temperature and spectral emissivity. This high spatial resolution temperature/emissivity information can be used to verify similar procedures employing MODIS data. Surface radiative temperature is an element in the radiative heat balance. Surface kinetic temperature can be used to determine elements of surface process models, sensible heat flux, latent heat flux, and ground heat conduction. Surface temperatures are also related to thermophysical properties (such as thermal inertia), vegetation health, soil moisture, temporal land classification (e.g., wet vs. dry, vegetated vs. bare soil), and evapotranspiration. ☆

Key ASTER Facts:

- Not scheduled for further flights
- Japan (MITI) to provide the instrument
- Prime Contractor: NEC (systems integration and VNIR)
- Subcontractors: MELCO (SWIR) and Fujitsu (TIR and cryocooler)

For Further Information:

Fujisada, H. and M. Ono, Overview of ASTER Design Concept, *Proceedings of the Society of Photo-Optical Instrumentation Engineers*, vol. 1490, April 1991.

Measurement Approach

Multispectral imager for reflected and emitted radiation, and measurements of Earth's surface
4% absolute radiometric accuracy in VNIR and SWIR bands
Absolute temperature accuracy is 3K in 200-240K range, 2K in 240-270K range, 1K in 270-340K range, and 2K in 340-370K range for TIR bands

Swath: 60 km at nadir, swath center is pointable cross-track ±106 km for SWIR and TIR, and ±314 km for VNIR
Spatial resolution: VNIR (0.5-0.9 μm), 15 m [stereo (0.7-0.9 μm), 15m horizontal, 25m vertical]; SWIR (1.6-2.5 μm), 30 m; TIR (8-12 μm), 90 m

Accommodation Issues

Mass: 400 kg
Duty cycle: 8% (VNIR and SWIR, daylight only), 16% (TiR)
Power: 449 W (average), 674 W (peak)
Data rate: 8.3 Mbps (average), 89.2 Mbps (peak)
Thermal control by: 80K Stirling cycle coolers, heaters, cold plate/capillary pumped loop, and radiators
Thermal operating range: 10-28°C

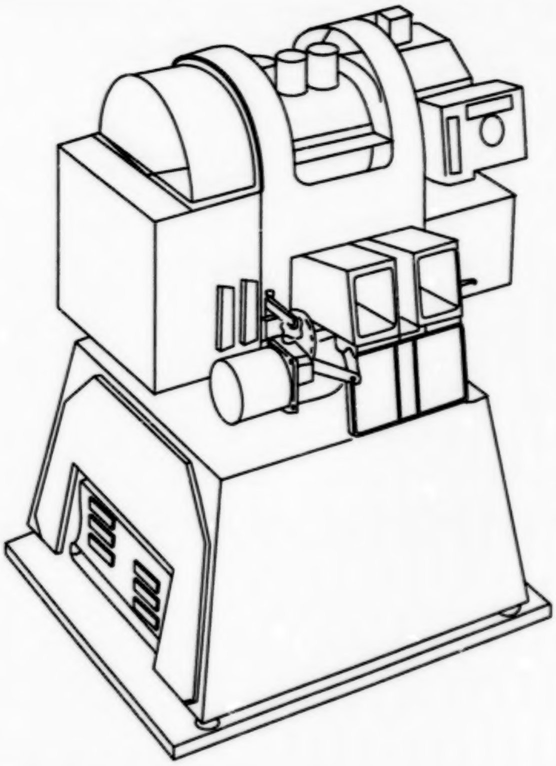
FOV (all pointing is near nadir, except VNIR both nadir and 27.6° backward from nadir):
  TIR = SWIR = 4.9° (nadir) x IFOV
  VNIR = 6.09° (nadir) x IFOV, 5.19° (backward) x IFOV
Instrument IFOV:
  SWIR = 43 μrad (nadir)
  TIR = 128 μrad (nadir)
  VNIR = 21 μrad (nadir), 18.1 μrad (backward)
Pointing requirements (platform+instrument, 3σ):
  Control: 1 km on ground (all axes)
  Knowledge: 422 m on ground (per axes)
  Stability: 2 pixels per 60 sec (roll = 8.8, pitch = 8.8, yaw - 15 arcsec)
  Jitter: 1-2 pixels per 9 sec (roll = 8.8, pitch = 4.4, yaw = 52 arcsec)
Physical size:
  VNIR = 53.8 x 65.1 x 83.2 cm
  SWIR = 73 x 124 x 95 cm
  TIR = 54 x 140 x 120 cm
  CSP/VEL (electronics) = 33.4 x 54 x 31.5 cm
  MPS (electronics) = 30 x 50 x 32 cm
Optics are sensitive to contamination

Team Members

Hiroji Tsu, Geological Survey of Japan (Team Leader)
Anne B. Kahle, Jet Propulsion Laboratory (U.S. Team Leader)
Kohei Arai, Saga University
Francois Becker, Universite Louis Pasteur de Strasbourg
Philip R. Christensen, Arizona State University
Hiroyuki Fujisada, Electrotechnical Laboratory
Kiyonari Fukue, Tokai University
Andy Gabell, CSIRO
Alan R. Gillespie, University of Washington
Ikahiro Hayashi, ERS Data Analysis Center
Jonathan Huntington, CSIRO
Yoshinori Ishii, Tokyo University
Hugh H. Kieffer, U.S. Geological Survey
Motoaki Kishino, Institute of Physical and Chemical Research
Shoichi Masuda, ERS Data Analysis Center
Yoshinori Miyazaki, Geological Survey of Japan
Akira Ono, National Research Laboratory of Meteorology
Frank Palluconi, Jet Propulsion Laboratory
David Pieri, Jet Propulsion Laboratory
Shuichi Rokugawa, Tokyo University
Lawrence C. Rowan, U.S. Geological Survey
John W. Salisbury, The Johns Hopkins University
Isao Sato, Geological Survey of Japan
Thomas Schmugge, USDA/Hydrology Laboratory
Philip N. Slater, University of Arizona
Teruyoshi Tagawa, ERS Data Analysis Center
Tsutomu Takashima, Meteorological Research Institute
Hiroshi Watanabe, Japan Geoscience Institute, Inc.
Ronald Welch, South Dakota School of Mines and Technology
Yasushi Yamaguchi, Geological Survey of Japan
Yoshifumi Yasuoka, National Institute for Environmental Studies

CERES

CLOUDS AND EARTH'S RADIANT ENERGY SYSTEM



TWO BROADBAND, SCANNING RADIOMETERS: ONE CROSS-TRACK MODE, ONE ROTATING PLANE

HERITAGE: ERBE

MEASURES EARTH'S RADIATION BUDGET AND ATMOSPHERIC RADIATION FROM THE TOP OF THE ATMOSPHERE TO THE SURFACE

THREE CHANNELS IN EACH RADIOMETER: TOTAL RADIANCE (0.3 TO >50 μM), SHORTWAVE (0.3 TO 5 μM), AND LONGWAVE (8 TO 12 μM)

The instruments of the CERES investigation will provide EOS with an accurate and self-consistent cloud and radiation database. Cloud and radiation flux measurements are fundamental inputs to models of oceanic and atmospheric energetics, and will also contribute to extended range weather forecasting. These data have been requested for international programs of the World Climate Research Program (WCRP), including the Tropical Ocean Global Atmosphere (TOGA) campaign, World Ocean Circulation Experiment (WOCE), and the Global Energy and Water Cycle Experiment (GEWEX).

Clouds are one of the largest sources of uncertainty in understanding climate. CERES will permit retrieval of cloud parameters in terms of measured areal coverage, altitude, liquid water content, and shortwave and longwave optical depths. CERES will use a longwave and shortwave threshold technique for 21-km resolution cloud retrievals. A retrieval with 4.5-μm band CO_2 radiances from other instrument measurements will improve detection of cirrus. Also, spatial coherence, hybrid bispectral threshold, and texture analysis will be used for further improving cloud property retrievals.

Surface radiation budget and atmospheric shortwave flux divergence will be computed using the relationship between the shortwave flux at the top of the atmosphere from CERES and the shortwave flux at the Earth's surface. Radiative transfer calculations and satellite measurements of atmospheric properties will be used to determine atmospheric flux divergence profiles; satellite-derived surface temperature and estimates of albedo and emissivity will be used to obtain longwave and shortwave components of the radiative fluxes at the Earth's surface.

Radiation will be provided as fluxes at the top of the Earth's atmosphere, at the Earth's surface, and as flux divergences within the atmosphere. Thus, these instruments will continue the long-term measurement of the Earth's radiation budget, and provide continuity with the Earth Radiation Budget Experiment (ERBE) and pre-ERBE measurements. Measurement of clear-sky fluxes will aid in the understanding of hypothesized climate forcing and feedback mechanisms involving surface radiative characteristics.

Geostationary satellite data will be used to fill in missing times and regions. Improved methods of time-space assimilation and interpolation across data voids will also be used. ☆

CERES Parameters

Measurement Approach

Measures longwave and shortwave infrared radiation using thermistor bolometers to determine the Earth's radiation budget

First instrument (cross-track scanning) will essentially continue the ERBE mission

Second instrument (biaxially scanning) will provide angular flux information that will improve accuracy of current models

Swath: Limb to limb
Spatial resolution: 21 km at nadir

Accommodation Issues

Mass: 90 kg [two scanners]
Duty cycle: 100%
Power: 95 W (average), 171 W (peak) [two scanners]
Data rate: 20 kbps [two scanners]
Thermal control by: Heaters, radiators
Thermal operating range: -15-35°C (electronics), 37-39°C (detectors)
FOV: ±78° cross-track, 360° azimuth
Instrument IFOV: 14 mrad

Pointing requirements (platform+instrument, 3σ):
Control: 720 arcsec
Knowledge: 180 arcsec
Stability: 79 arcsec/6.6 sec
Physical size: 60 x 60 x 57.6 cm/unit (stowed); 60 x 60 x 70 cm/unit (deployed)

Key CERES Facts:

- Also scheduled for the TRMM-1 mission (1997)
- Dual scanners on EOS-AM1 and -PM1, single thereafter
- Phase C/D start January 1991
- Prime Contractor: TRW
- Responsible Center: LaRC

For Further Information:

Barkstrom, B.R., Long-Term Monitoring of the Earth's Radiation Budget, in *Proceedings of the Society of Photo-Optical Instrumentation Engineers*, vol. 1299, Bellingham, WA, 1990.

Principal Investigator—Bruce Barkstrom

Bruce Barkstrom received a B.S. in Physics from the University of Illinois. He received an M.S. and Ph.D. in Astronomy from Northwestern University. Following a position as Research Associate with the National Center for Atmospheric Research, he had a 5-year teaching assignment with George Washington University. In 1979, Dr. Barkstrom joined NASA/Langley Research Center. He serves as the ERBE Experiment Scientist and Science Team Leader. As such, he was directly responsible for the ERBE instrument design and calibration, as well as the ERBE data interpretation. He was also responsible for science project management of the ERBE team of 17 Principal and 40 Co-Investigators.

Co-Investigators

Maurice L. Blackmon, NOAA/Environmental Research Laboratory
Robert D. Cess, State University of New York–Stony Brook
Thomas P. Charlock, Langley Research Center
James A. Coakley, Oregon State University
Dominique Crommelynck, Royal Meteorological Institute
Wayne L. Darnell, Langley Research Center
Richard N. Green, Langley Research Center
Edwin F. Harrison, Langley Research Center
Robert S. Kandel, Ecole Polytechnique
Michael D. King, Goddard Space Flight Center
Robert B. Lee III, Langley Research Center
Alvin J. Miller, NOAA/National Weather Service
Patrick Minnis, Langley Research Center
Veerabhadran Ramanathan, Scripps Institution of Oceanography
David A. Randall, Colorado State University
G. Louis Smith, Langley Research Center
Larry L. Stowe, NOAA/National Environmental Satellite, Data, and Information Service
Ronald Welch, South Dakota School of Mines and Technology
Bruce A. Wielicki, Langley Research Center

Selected for Flight on EOS-ALT Series

DORIS, SSALT, and TMR

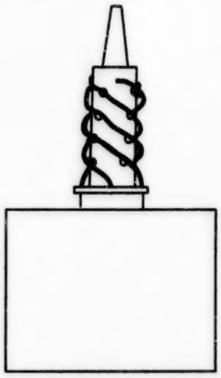
DOPPLER ORBITOGRAPHY AND RADIOPOSITIONING INTEGRATED BY SATELLITE, SOLID-STATE ALTIMETER, AND TOPEX MICROWAVE RADIOMETER

DORIS

PRECISION ORBIT DETERMINATION SYSTEM

HERITAGE: TOPEX/POSEIDON, SPOT-2

PROVIDES ORBITAL POSITIONING INFORMATION AND IONOSPHERIC CORRECTION FOR SSALT



Doppler Orbitography and Radiopositioning Integrated by Satellite

Solid-State Altimeter

SSALT

SINGLE-FREQUENCY RADAR ALTIMETER

HERITAGE: TOPEX/POSEIDON

MAPS THE TOPOGRAPHY OF THE SEA SURFACE AND POLAR ICE SHEETS

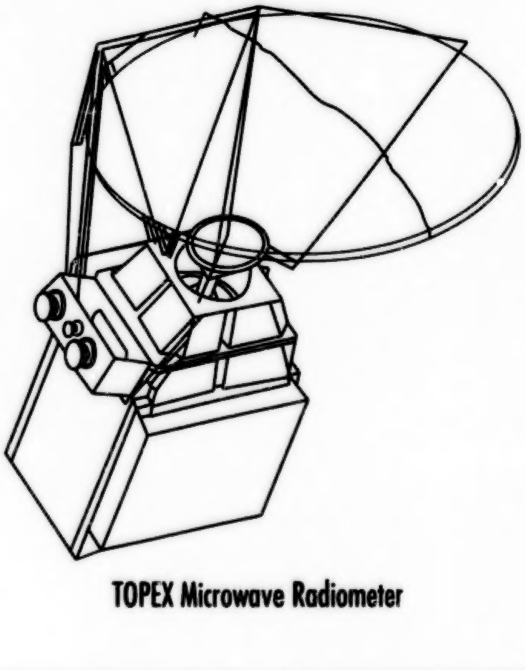
MEASURES OCEAN WAVE HEIGHT AND WIND SPEED, AND PROVIDES INFORMATION ON THE OCEAN SURFACE CURRENT VELOCITY

TMR

MICROWAVE RADIOMETER

HERITAGE: TOPEX/POSEIDON, SEASAT, NIMBUS-7

PROVIDES ATMOSPHERIC WATER VAPOR PROFILE MEASUREMENTS FOR SSALT



TOPEX Microwave Radiometer

DORIS

DORIS is a dual doppler receiver tracking system operated by the Centre National d'Etudes Spatiales (CNES). The DORIS receiver acquires precision tracking data by listening at two frequencies for signals from a worldwide network of CNES DORIS orbit determination beacons. The instrument determines the satellite velocity by measuring the doppler shifts of two ultra-stable microwave frequencies (401.25 and 2,036.25 MHz), which are transmitted by the French beacons. Positions of the ground-based beacons are known within a few cm. Approximately 50 global all-weather radio beacons are currently in operation.

The DORIS system measures one-way range-rate from the ground station to the satellite. The ground stations transmit at frequencies of 2 GHz and 400 MHz. The separation of the two transmitting frequencies makes it possible to reduce the ionospheric effect to around the centimeter level. Tropospheric refraction is modeled using surface meteorological data from the ground stations which are directly transmitted to the satellite.

DORIS was validated by a prototype flown on the Systeme pour l'Observation de la Terre-2 (SPOT-2) satellite, launched in January 1990. It has already provided over 6 million measurements, which have been used to refine data-processing methods and to improve models of the Earth's gravity field. A DORIS instrument now operates aboard the Ocean Topography Experiment (TOPEX)/Poseidon spacecraft, a joint mission between the U.S. and France launched in August 1992.

The DORIS instruments slated for the EOS-ALT series will be similar to those aboard TOPEX/Poseidon. Experience with SPOT-2 and TOPEX/Poseidon has shown that the instrument operates most efficiently at an altitude between 750 and 1,500 km. However, DORIS can operate from 300 km to several thousand km.

SSALT

SSALT is a nadir-looking radar altimeter that maps the topography of the sea surface and polar ice sheets. The shape and strength of the radar return pulse also provide measurements of ocean wave height and wind speed, respectively. Through the mapping of sea surface topography, SSALT provides information on the ocean surface current velocity, which when combined with ocean models, can lead to a four-dimensional description of ocean circulation. The heat and biogeochemical fluxes carried by ocean currents hold the key to understanding the ocean's role in global changes in climate and biogeochemical cycles. Secondary research contributions include the study of the variations in sea level and ice sheet volume in response to global warming/cooling and hydrological balance; the study of marine geophysical processes (such as crustal deformation) from the sea surface topography; and the monitoring of global sea state from the wave height and wind speed measurement.

SSALT was developed by Alcatel Espace Systems (ATES) under contract from CNES Toulouse Space Center. This altimeter is being flown on TOPEX/Poseidon as an experimental instrument to allow validation of the accuracy, operation, and signal processing of a small-volume, lightweight, low-power altimeter. SSALT uses the same antenna as the NASA Altimeter (ALT) aboard TOPEX/Poseidon, but operates at the single frequency of 13.6 GHz. The ionospheric-electron correction is provided by a model that makes use of the simultaneous dual-frequency measurements of the DORIS tracking system. Both the operating principles and the expected performance of the NASA and CNES altimeters are similar; however, SSALT has only one-fourth the mass, volume, and power consumption of the NASA instrument. Moreover, the telemetry data rate is reduced by a factor of seven because of more extensive onboard processing. SSALT should be considered a prototype in its present application, but a flight-proven concept by the time of the first EOS-ALT launch in 2002.

Altimetric measurement by radar determines the distance of the satellite from the surface of the sea. The slope of the surface can then be inferred, which is directly related to the speed of ocean currents. Information on wave height and wind speed can also be obtained. SSALT will help establish global, long-term trends of ocean currents, which will assist in weather prediction and understanding of the hydrologic cycle.

TMR

Altitude accuracy (as determined by the altimeters aboard EOS-ALT) is affected by the variable water content of the atmosphere, mainly the troposphere. The primary TMR objective involves measuring the radiometric brightness temperature related to water vapor and liquid water in the same field-of-view as the altimeter. In turn, these brightness temperatures are converted to path-delay information required by the altimeter for precise topography measurements. In order to achieve the required 1.2-cm path-delay, the absolute accuracy required of TMR is 0.5K.

TMR will continuously measure microwave radiation, and derived data will be used to determine water vapor and liquid water content in the altimeter field-of-view. TMR consists of a collecting aperture, whose pointing axis is aligned collinear with the pointing axis of the altimeter sensor; a multifrequency feed assembly that illuminates the collecting aperture; multichannel microwave receivers; a data unit; power supplies; and ground support equipment.

Developed by the Jet Propulsion Laboratory (JPL), TMR operates at frequencies of 18, 21, and 37 GHz to provide estimates of total atmospheric water vapor content. By operating simultaneously on three frequencies, the columnar path-delay is derived from microwave brightness temperature. The 21 GHz frequency is the primary measurement channel; the 18 and 37 GHz channels are used to remove the effects of wind speed and cloud cover, respectively. The 21 GHz channel is redundant. Each channel also has redundant power supplies. These data allow reduction of the water vapor delay error to 1 cm, permitting an overall altimetric precision of 3 cm. The three radiometer channel outputs are combined, along with engineering data, in a redundant digital programmer. The TMR instrument utilizes modified and refurbished hardware from the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR); however, the data chassis (i.e., digital programmer, analog multiplexer, and satellite interface circuitry) is new. In-flight calibration is provided by periodically measuring the brightness temperature of the cosmic background (2.7K) and the brightness temperature of an internal matched microwave termination (~300K). Post-launch verification is performed through the use of an upward-looking water vapor radiometer located at selected verification sites. ☆

DORIS Parameters

Measurement Approach

Onboard DORIS receiver accurately measures the doppler shift on both transmitted frequencies (401.25 and 2,036.25 MHz) received from an orbit determination beacon (ODB) station

Network of ~50 ODBs located worldwide

Accommodation Issues

Mass: 44 kg

Duty cycle: 100%

Power: 17.6 W (receiver, 14.3 W; USO, 3.3 W at 20°C)

DC supply bus: Unregulated 23-35 V

Data rate: 31.25 bps

Thermal control by: Heat transfer by conduction to mounting surface and by radiation within the instrument module

Thermal operating range: -10-50°C

IFOV: 120° cone (centered on nadir)

Pointing requirements (platform+instrument, 3σ):

Control: 1.5°

Knowledge: 0.2° (depending on the distance between the antenna phase center and the satellite center of mass)

Physical size: 28 x 40 x 21 cm (receiver);
8 x 16 x 8 cm (USO);
33 x 35 x 4 cm (baseplate for two USOs)

Antenna envelope: 39 cm long x 32 cm cylindrical

Key DORIS Facts:

- Also flies on TOPEX/Poseidon and SPOT-2
- Ready for launch on SPOT-3 and installation on SPOT-4
- Prime Contractors: Dassault Electronique (receiver), CEIS Espace (beacons), OSA and CEPE (USOs), and STAREC (antennas)
- Responsible Center: CNES

Key SSALT Facts:

- Also flies on TOPEX/Poseidon
- Prime Contractor: ATES
- Responsible Centers: CNES

Key TMR Facts:

- Also flies on TOPEX/Poseidon
- In-house JPL development

For Further Information:

TOPEX/Poseidon Project, Specific Sensor Interface Specification (SSIS) for the DORIS Receiver, 968-GR1017, Rev. B.

TOPEX/Poseidon Project, Specific Sensor Interface Specification (SSIS) for the Solid-State Altimeter (SSALT), 968-GR1016, Rev. B.

Raizonville, P. *et al*, Poseidon Radar Altimeter Flight Model and Design Test Results, *Proceedings of the International Geoscience and Remote-Sensing Symposium*, Washington, DC, 1992.

TOPEX/Poseidon Project, Microwave Radiometer Functional Requirements, 633-446, Rev. A (JPL D-5640, Rev. A).

SSALT Parameters

Measurement Approach
Transmitted pulse width of 105 µsec
Nominal radio frequency output power to antenna of +37 dBm
Pulse repetition frequency of 1.7 kHz

Accommodation Issues*
Mass: 25 kg (12 kg, PU; 13 kg, MU)
Duty cycle: 100%
Power: 49 W
DC supply bus: Unregulated 23-35 V
Transmission frequency: 13.65 GHz
Data rate: 1.375 kbps (operating), 11.5 kbps (calibrating)
Thermal operating range: -5-35°C
Thermal control by: Heat transfer by conduction to mounting surface and by radiation within the instrument module
IFOV: 20° cone (centered on nadir)
Pointing requirements (platform+instrument, 3σ):
  Control: <0.2°
  Knowledge: <0.1°
Physical size: 36.5 x 28.8 x 23.2 cm (MU);
  35.5 x 25.5 x 20.3 cm (PU)

*Note: On TOPEX/Poseidon, SSALT shared an antenna with ALT—a 1.5-m parabolic reflector with a circular, linear-polarized beam, antenna mass of 17.5 kg

TMR Parameters

Measurement Approach
Total water vapor along the path viewed by the altimeters
Corrects altimeter data for pulse delay due to water vapor
Derived by measuring the brightness temperatures in the nadir column at 18, 21, and 37 GHz
Beamwidth: 1.8° at 18 GHz, 1.5° at 21 GHz, and 1.3° at 37 GHz
Temperature resolution: ≤0.3K
System temperature: 800K

Accommodation Issues
Mass: 50 kg
Duty cycle: 100%
Power: 26 W
DC supply bus: Unregulated 23-35 V
Data rate: 125 bps
Thermal control by: Titanium mounting struts that thermally isolate the instrument from the spacecraft; control maintained by thermal blankets and variable louvres to space; heaters available for non-operating conditions
Thermal operating range: 5-40°C
Pointing requirements (platform+instrument, 3σ):
  Control: <0.3° (electrical boresight to SSALT boresight)
  Knowledge: <0.5°
  Stability: <0.5°
  Jitter: <0.5°
Physical size: 35 x 51 x 61 cm (electronics);
  30 x 91 cm (sun shield envelope)

Calibration horn has 60° cone centered at nadir and a 80° cone to cold space (should not view Earth)

Team Leader—To Be Determined (U.S.)

The EOS-ALT mission is a collaborative effort between NASA and CNES, with the details of the partnership currently being negotiated. NASA will select the U.S. Team Leader and science team members through a competitive peer review process, evaluating the merit of U.S. proposals to use data from these instruments to address key issues in global climate change. CNES will identify the French scientists who will participate as team members and the individual to serve as the French Team Leader. In the interim period, Dr. Lee-Lueng Fu, who is currently the TOPEX/Poseidon Team Leader, will serve as the U.S. Point-of-Contact for scientific issues related to these instruments.

Lee-Lueng Fu received a B.S. in Physics from the National Taiwan University in 1972, and a Ph.D. in Oceanography from MIT and WHOI in 1980. He has been with JPL since 1980, and is currently Supervisor of the Physical Oceanography Group, Atmospheric and Oceanography Sciences Section. Dr. Fu's research interests involve analyzing satellite remote-sensing observations for the study of ocean currents and waves. Dr. Fu is a Principal Investigator on the science teams of the NSCAT Project and the TOPEX/Poseidon mission. In recognition of his research, he was the recipient of the JPL Director's Research Achievement Award in 1986.

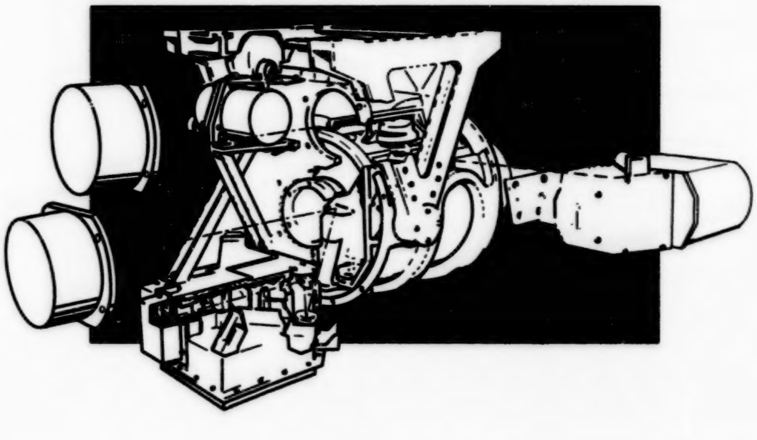
Team Members

U.S. team membership will be determined through a competitive, peer-review process of scientific investigations that require data from these instruments. The selected investigators and those identified by CNES will comprise the international science team.

Selected for Flight as EOS-COLOR

EOS-COLOR

EOS OCEAN COLOR INSTRUMENT



ADVANCED OCEAN COLOR IMAGER

FURTHERS UNDERSTANDING OF THE ROLE OF OCEANS IN THE GLOBAL CARBON CYCLE, FLUXES OF TRACE GASES AT THE AIR-SEA INTERFACE, AND OCEAN PRIMARY PRODUCTIVITY

HERITAGE: CZCS, SEAWIFS

FOLLOW-ON TO THE SEASTAR/SEAWIFS MISSION (1993 LAUNCH)

ALSO A DATA PURCHASE (1998 LAUNCH)

The EOS Ocean Color Instrument is a second generation sensor, based on the Coastal Zone Color Scanner (CZCS) on Nimbus-7 and the SeaStar/Sea-Viewing Wide Field Sensor (SeaWiFS) planned for launch in 1993. SeaStar/SeaWiFS is being conducted as a NASA data purchase from a commercial satellite operator. The EOS-COLOR mission (with a sole SeaWiFS-type instrument as its payload) has been approved to maintain continuity of the data set. EOS-COLOR will have the same basic specifications as the SeaStar/SeaWiFS mission; however, the instrument developer and/or operator have yet to be determined. Instrument specifications include the following:

- Near-polar, sun-synchronous, descending orbit; 705-km altitude; noon±15 min equatorial crossing time
- Visible, near-infrared ocean color imager, with +20°, 0°, and -20° scan plane tilt, four gain settings (x1, x2, lunar, and solar diffuser), solar diffuser, and lunar view calibration
- 100 percent duty cycle over daylight portions of the Earth
- 1.1-km global coverage at nadir, with a swath of ±58.3° (2,800 km)
- Direct broadcast in a High-Resolution Picture Transmission (HRPT)-like format.

Local, high-resolution data will be available via direct broadcast; recorded global data coverage will be transmitted to a ground station, then forwarded to Goddard Space Flight Center (GSFC) for analysis and distribution. These data will be used to study ocean biogeochemistry and its role in the global carbon cycle and as a feedback on physical phenomena, such as heat storage in the upper ocean and cloud albedo. Specific science objectives are to:

- Determine the magnitude and variability of the annual cycle of primary production by marine phytoplankton on a global scale
- Quantify the role of oceans in the global carbon and biogeochemical cycles
- Quantify relationships between ocean physics and large-scale patterns of productivity
- Determine the distribution and timing of spring phytoplankton blooms
- Visualize the physics behind mixing of ocean and coastal currents and eddies
- Advance scientific and technical capability in satellite ocean color observation, data processing, and analysis. ☆

EOS-COLOR Parameters

Measurement Approach

Single eight-channel opto-mechanical scanner with viewing angles of +20°, 0°, and -20° in the velocity direction
Eight spectral bands in the range 402-885 nm
Radiometric accuracy <5% absolute each band
Frequent solar calibration; monthly lunar calibration
Relative precision <1% linearity of signal output to radiance
Precision <5% band to band (over 0.5-0.9 full scale)
Polarization sensitivity <2% worst case, all scan and tilt angles
Bright target recovery <10 samples
Dynamic range of 10 bits; four gain settings in each channel (0.75, 1.0, 1.5, 2.5)
Pixel location knowledge 1.0 km
Noon±15 minute equatorial crossing time, descending orbit

Swath width: 2,800 km (±58.3°) provides daily global coverage
Spatial resolution: 1.1 km (LAC) and 4.5 km (GAC)

Spectral Bands (minimum specification)

Band	Wavelength Range (nm)	Saturation Radiance*	Input Radiance*	SNR**
1	402-422	13.63	9.10	499
2	433-453	13.25	8.41	674
3	480-500	10.50	6.56	667
4	500-520	9.08	5.64	640
5	545-565	7.44	4.57	596
6	660-680	4.20	2.46	442
7	745-785	3.00	1.61	455
8	845-885	2.13	1.09	467

* mW/cm^2 µm steradian, gain 1
** Measured at input radiance, at all tilt and sun angles
SNR is the mean of 100 samples divided by the standard deviation of the samples at a specified input radiance

EOS-COLOR Science Team

The members of the Moderate-Resolution Imaging Spectroradiometer (MODIS) Science Team who possess an ocean research emphasis are currently advising NASA on ocean color missions, and will become members of the EOS-COLOR Science Team. NASA will solicit additional proposals and, through a peer review process, select the scientists and Principal Investigator who will lead studies using EOS-COLOR data. In tandem, these investigators will form the EOS-COLOR team, advising NASA on ocean color mission requirements and assuming responsibility for algorithm development for the EOS-COLOR mission.

Key EOS-COLOR Facts:

- Data purchase mission
- Launch scheduled for 1998
- Instrument developer and/or operator yet to be determined

For Further Information:

NASA Research Announcement, Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) Global Ocean Primary Production, Office of Space Science and Applications, NRA-92-OSSA-7, April 29, 1992.

Selected for Flight on EOS-AM2 and -AM3

EOSP

EARTH OBSERVING SCANNING POLARIMETER

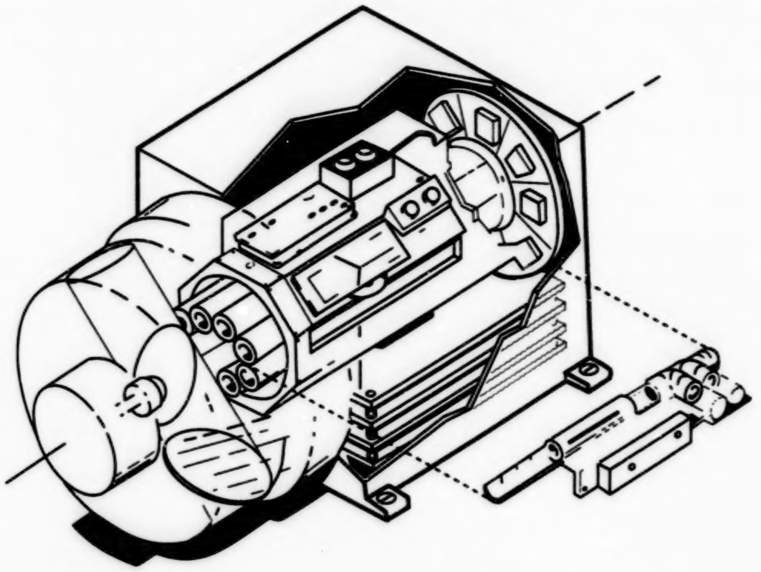
CROSS-TRACK SCANNING POLARIMETER

HERITAGE: PIONEER VENUS CPP, GALILEO PPR

GLOBALLY MAPS RADIANCE AND LINEAR POLARIZATION OF REFLECTED AND SCATTERED SUNLIGHT FOR 12 SPECTRAL BANDS FROM 0.41 TO 2.25 µm

PROVIDES GLOBAL AEROSOL DISTRIBUTION

PROVIDES CLOUD PROPERTIES SUCH AS OPTICAL THICKNESS AND PHASE



EOSP will provide global maps of cloud and aerosol properties from retrievals of 12-channel radiance (0.41 to 2.25 µm) and polarization measurements in the visible and near-infrared. EOSP employs cross-track, limb-to-limb scanning with contiguous 10-km nadir instantaneous field-of-view. The polarization and radiance measurements, combined with phase angle information, will be used to retrieve cloud and aerosol properties, including optical thickness, particle size, liquid/ice phase, and cloud-top pressure. EOSP measurements will also be used to retrieve global aerosol distribution and optical thickness in the troposphere and stratosphere. These data will provide atmospheric corrections for clear-sky ocean and land observations, and will also be applied to the study of vegetation and land surface characteristics.

The significant feature of EOSP as compared to other EOS instruments is its use of polarimetry in addition to intensity measurements; previous instrumentation relied solely on radiance intensity measurements. Polarization is significantly more sensitive to particle size and optical properties than is intensity. Analysis of EOSP signals will proceed in two phases. In the first phase, a "cloud" algorithm will be used to divide data into the two optical depth ranges that generally separate water clouds from other aerosols. This separation will make use of intensity and polarization information in all 12 EOSP spectral bands. A combination of intensity and polarization measurements will lead to determination of cloud optical thickness. For optically thin clouds, polarization is known to be a much more sensitive measure of optical thickness. Cloud-top pressure determinations are based on measurements of Rayleigh scattering, which is proportional to the pressure. Water clouds give a distinct "rainbow" polarization signal, whereas ice clouds do not, thus providing the basis for particle-phase determination. For water clouds, the strength and precise location in phase angle of the rainbow feature determine cloud particle size.

Aerosol optical thickness will be calculated from measurements taken of cloud-free areas. The determination will be based on the characteristic behavior of polarization (i.e., optically thinner layers exhibit higher polarization degree). This is particularly true in the expected regions having optical thickness 0.01 to 1. The quantification of aerosol properties also provides atmospheric correction information, a significant by-product of importance to the surface imagers on the EOS platform. EOSP will complement the Moderate-Resolution Imaging Spectroradiometer (MODIS), exchanging the high-accuracy polarimetry of EOSP for the more extensive spectral coverage and higher spatial resolution obtained by MODIS. On the other hand, MODIS observations may be used to deal with the scene variability that will be encountered in the broader EOSP field-of-view. The technique used here will be to compile a global aerosol climatology, then parameterize the corrections for a limited number of typical situations. The use of polarimetry for characterization of vegetation and land is to be the subject of exploratory investigation.

EOSP products will fall into three major categories: Atmospheric cloud properties, aerosol properties, and atmospheric correction radiances to be furnished to the other surface imagers on the EOS platform. EOSP data products will include the following:

- Cloud-top pressure, with 30-m vertical resolution and 40-km horizontal resolution
- Cloud particle phase at cloud top, with 100-km horizontal resolution
- Cloud particle size at cloud top, with 100-km horizontal resolution
- Cloud optical thickness, with 40-km horizontal resolution
- Aerosol optical thicknesses at an altitude range of 0 to 35 km, with 40-km horizontal resolution
- Atmospheric correction radiances covering the spectral region from 0.41 to 2.25 µm, with 40-km horizontal resolution.

One global map per day will be furnished for each of the EOSP products. ☆

Key EOSP Facts:

- Phase C/D start expected second quarter of 1994
- Algorithm development to take place for the next 2 years
- Responsible Center: GSFC

For Further Information:

Brown, F.G. and E.E. Russell (Santa Barbara Research Center), Earth Observing Scanning Polarimeter, Phase B Final Report, Contract #NAS5-30756, DM LB870016, December 1990.

EOSP Parameters

Measurement Approach

Simultaneous measurement of radiance and linear polarization degree in 12 spectral bands from 0.41 to 2.25 µm
Spectral bidirectional reflectance distribution function accurate to 5%
Polarization accurate to 0.2%

Swath: ±65° (limb-to-limb scan)
Spatial resolution: 10 km at nadir

Accommodation Issues

Mass: 19 kg
Duty cycle: 100%
Power: 14 W (normal), 22 W (peak)

Data rate: 44 kbps (orbit average), 88 kbps (peak, daylight only)
Thermal control by: Heaters and radiators; 185K radiator for SWIR detector cold focal plane
Thermal operating range: 0-40°C
FOV: ±65° cross-track
Instrument IFOV: 14.2 mrad
Pointing requirements (platform+instrument, 3σ):
Control: 3,600 arcsec
Knowledge: 150 arcsec
Stability: 100 arcsec per 10 arcsec
Jitter: 100 arcsec per 10 sec
Physical size: 51 x 26 x 81 cm (stowed); 51 x 56 x 81 cm (deployed)

Principal Investigator—Larry D. Travis

Larry D. Travis received a Ph.D. from Pennsylvania State University in 1971. He is currently the Associate Chief at the NASA Goddard Institute for Space Studies. His research interests include radiative transfer single and multiple scattering theory, theoretical interpretation of planetary polarization, and satellite platform measurements of planetary polarization. Dr. Travis serves as Principal Investigator for the Pioneer Venus Cloud Photopolarimeter Experiment and as a Co-Investigator for the Galileo Photopolarimeter Radiometer Experiment.

Co-Investigators

F. Gerald Brown, Santa Barbara Research Center
Andrew Lacis, Goddard Institute for Space Studies
William B. Rossow, Goddard Institute for Space Studies
Edgar E. Russell, Santa Barbara Research Center

Selected for Flight on EOS-ALT Series

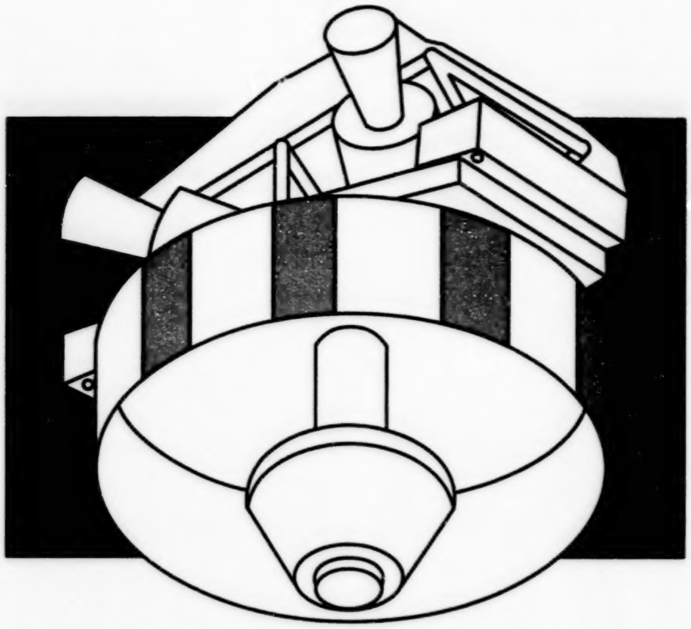
GLAS

GEOSCIENCE LASER ALTIMETER SYSTEM

NADIR-POINTED LASER ALTIMETER

HERITAGE: AIRBORNE AND SPACEBORNE LASER ALTIMETRY AND LIDAR SYSTEMS; SATELLITE LASER RANGING SYSTEMS

MEASURES ICE SHEET TOPOGRAPHY AND TEMPORAL CHANGES IN TOPOGRAPHY; CLOUD HEIGHTS, PLANETARY BOUNDARY HEIGHTS, AND AEROSOL VERTICAL STRUCTURE; AND LAND AND WATER TOPOGRAPHY



GLAS is a laser altimeter designed to measure ice-sheet topography and associated temporal changes, as well as cloud and atmospheric properties. In addition, operation of GLAS over land and water will provide along-track topography. GLAS is a descoped version of the Geoscience Laser Ranging System (GLRS), focusing solely on the laser altimetry science mission. For ice-sheet applications, the laser altimeter will measure height from the spacecraft to the ice sheet, with an intrinsic precision of better than 10 cm with a 70-m surface spot size. The height measurement, coupled with knowledge of the radial orbit position, will provide the determination of topography. Characteristics of the return pulse will be used to determine surface roughness. Changes in ice-sheet thickness at a level of a few tens of cm (anticipated to occur on a subdecadal time scale) will provide information about ice-sheet mass balance and will support prediction analyses of cryospheric response to future climatic changes. The ice-sheet mass balance and contribution to sea level change will also be determined. The accuracy of height determinations over land will be assessed using ground slope and roughness. The height distribution will be digitized over a total dynamic range of several tens of m.

Along-track cloud and aerosol height distributions will be determined with a vertical resolution of 75 to 200 m and a horizontal resolution from 150 m for dense cloud to 50 km for aerosol structure and planetary boundary layer height. Unambiguous measurements of cloud height and the vertical structure of thin clouds will support studies on the influence of clouds for radiation balance and climate feedbacks. Polar clouds and haze will be detected and sampled with much greater reliability and accuracy than can be achieved by passive sensors. Planetary boundary layer height will be directly and accurately measured for input into surface flux and air-sea and air-land interaction models. Direct measurements of aerosol vertical profiles will contribute to understanding of aerosol-climate effects and aerosol transport.

The GLAS laser is a frequency-doubled, cavity-pumped, solid-state Nd:YAG laser with energy levels of 120 mJ (1.064 μm) and 60 mJ (0.532 μm). The pulse repetition rate is 40 pulses/sec, and the beam divergence is approximately 0.1 mrad. The infrared pulse is used for surface altimetry, and the green pulse is used for atmosphere measurements. The altimeter uses a 90-cm diameter telescope. ☆

Key GLAS Facts:
- GSFC in-house development
- Phase C/D start expected first quarter of 1995

For Further Information:
Cohen, S., J. Degnan, J. Bufton, J. Garvin, and J. Abshire, The Geoscience Laser Altimetry/Ranging System, *IEEE Trans. Geoscience Remote Sensing*, GE-25, 581-592, 1987.

GLAS Parameters

Measurement Approach

Uses Nd:YAG laser with 1.064- and 0.532-µm output

Height measurements are determined from the round-trip pulse time of the infrared pulse flight

Cloud and aerosol data are extracted from the green pulse

Swath: Nadir viewing

Spatial resolution: At 40 pulses per second, the centers of 70-m spots are separated in the along-track direction by 188 m for a 705-km altitude orbit; the cross-track resolution is determined by the ground-track separation

Accommodation Issues

Mass: 125 kg

Duty cycle: 50% average, 100% capability for extended periods

Power: 175 W average

Data rate: <200 kbps

Thermal control by: Radiators supplemented by heaters

Thermal operating range: 0-25°C

FOV: Nadir only

Instrument IFOV: ~70-m laser footprint at nadir at 1.064 µm

Pointing requirements (platform+instrument, 3σ):

- Control: ~90 arcsec (all axes)
- Post-processing knowledge: 5 arcsec (all axes, to be provided by instrument-mounted star trackers)
- Real-time knowledge: 10 arcsec
- Stability: 2 arcsec/sec
- Jitter: <2 arcsec for periods less than 1 sec

Position requirements: Post-processing determination of radial orbit for ice sheet to ~10 cm and along-track position to ~3 m (to be provided by instrument-mounted GPS receiver and SLR array)

Physical size: 100 x 100 x 80 cm

Contamination concerns exist regarding altimeter telescope and laser optics train

Team Leader—Bob E. Schutz

Bob Schutz received a Ph.D. in 1969. Currently, he is Professor of Aerospace Engineering and Engineering Mechanics at the University of Texas–Austin, and holds the Gulf Oil Foundation Centennial Fellowship in Engineering. He is also Associate Director of the Center for Space Research and a member of the Applied Research Laboratory staff, both of which are components of the University of Texas–Austin.

Dr. Schutz is active in research pertaining to the application of satellite data to the areas of geodesy, geophysics, and oceanography. He has extensive experience in the analysis of laser ranging measurements from the Laser Geodynamics Satellite (LAGEOS) and other satellites, radar altimeter measurements collected from Seasat and Geosat, and measurements obtained from the Global Positioning System (GPS). He has been instrumental in the development of software for studies in crustal motions, sea surface topography, orbital dynamics, variations in Earth rotation, and temporal changes in the Earth gravity field.

Dr. Schutz serves as the President of the International Association of Geodesy and COSPAR Commission on the International Coordination of Space Techniques for Geodesy and Geodynamics. He is also the Satellite Laser Ranging Coordinator for the International Earth Rotation Service and a member of the International Astronomical Union Commission 19.

Team Members

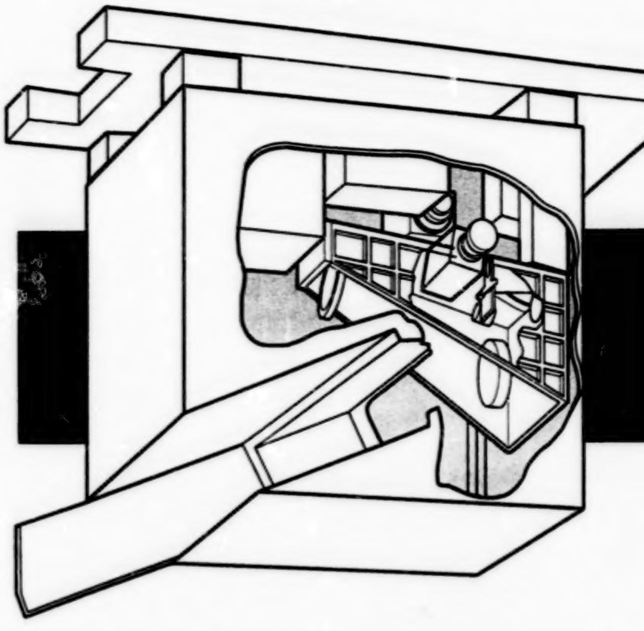
GLAS is a descoped component of GLRS-A. The science team members identified during the definition phase were selected to conduct investigations in the area of laser altimetry and ranging. Since the ranging component of this instrument was deleted, the investigations focusing on this subject are no longer relevant and will be deselected. The following list offers the science team chosen for GLRS-A, with ultimate composition to be determined by the spring of 1993:

Charles R. Bentley, University of Wisconsin–Madison
Michael G. Bevis, North Carolina State University
Jack L. Bufton, Goddard Space Flight Center
Steven Cohen, Goddard Space Flight Center
Thomas A. Herring, Massachusetts Institute of Technology
Jean-Bernard Minster, Scripps Institution of Oceanography
William H. Prescott, U.S. Geological Survey
Robert E. Reilinger, Massachusetts Institute of Technology
James D. Spinhirne, Goddard Space Flight Center
Robert H. Thomas, NASA Headquarters
H. Jay Zwally, Goddard Space Flight Center

HIRDLS

HIGH-RESOLUTION

DYNAMICS LIMB SOUNDER



OBSERVES GLOBAL DISTRIBUTION OF TEMPERATURE AND CONCENTRATIONS OF O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC_{11}, CFC_{12}, $ClONO_2$, AND AEROSOLS IN THE UPPER TROPOSPHERE, STRATOSPHERE, AND MESOSPHERE

SPECTRAL RANGE 6 TO 18 μM

STANDARD PROFILE SPACING 4° LONGITUDE x 4° LATITUDE, AND 1-KM VERTICAL RESOLUTION; PROGRAMMABLE TO OTHER MODES AND RESOLUTION

HERITAGE: LRIR (NIMBUS-6), LIMS AND SAMS (NIMBUS-7), ISAMS AND CLAES (UARS)

HIRDLS is an infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine temperature; the concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC_{11}, CFC_{12}, and aerosols; and the locations of polar stratospheric clouds and cloud tops. The goals are to provide sounding observations with horizontal and vertical resolution superior to that previously obtained; to observe the lower stratosphere with improved sensitivity and accuracy; and to improve understanding of atmospheric processes through data analysis, diagnostics, and use of two- and three-dimensional models.

HIRDLS performs limb scans in the vertical at multiple azimuth angles, measuring infrared emissions in 21 channels ranging from 6.12 to 17.76 μm. Four channels measure the emission by CO_2. Taking advantage of the known mixing ratio of CO_2, the transmittance is calculated, and the equation of radiative transfer is inverted to determine the vertical distribution of the Planck black body function, from which the temperature is derived as a function of pressure. Once the temperature profile has been established, it is used to determine the Planck function profile for the trace gas channels. The measured radiance and the Planck function profile are then used to determine the transmittance of each trace species and its mixing ratio distribution.

Winds and potential vorticity are determined from spatial variations of the height of geopotential surfaces. These are determined at upper levels by integrating the temperature profiles vertically from a known reference base. HIRDLS will improve knowledge of data-sparse regions by measuring the height variations of the reference surface provided by conventional sources with the aid of a gyro package. This level (near the base of the stratosphere) can also be integrated downward using nadir temperature soundings to improve tropospheric analyses.

Overall science goals of HIRDLS are to observe the global distributions of temperature and several trace species in the stratosphere and upper troposphere at high vertical and horizontal resolution. Specific issues to be investigated include:

- Fluxes of mass and chemical constituents between the troposphere and stratosphere
- Chemical processes, transport, and mixing by day and night (particularly in the lower stratosphere)
- Momentum, energy, heat, and potential vorticity balances of the upper troposphere and middle atmosphere
- Geographically and seasonally unbiased long-term climatologies and interannual variability of middle atmosphere temperature, constituents, dynamical fields, and gravity waves
- Tropospheric cloud-top heights
- Tropospheric temperature and water vapor retrievals (by providing high-resolution limb data for joint retrieval with EOS nadir sounders)
- Diagnostic studies of atmospheric dynamics, chemistry, and transport processes to test and improve models of these processes.

The instrument has a long heritage extending back to Nimbus-4, and will obtain profiles over the entire globe, including the poles, both day and night. Complete Earth coverage (including polar night) can be obtained in 12 hours. High horizontal resolution is obtained with a commandable azimuth scan which, in conjunction with a rapid elevation scan, provides a 2,000- to 3,000-km-wide swath of profiles along the satellite track. Vertical profiles are spaced every 4° in latitude and longitude, with 1- to 1.5-km resolution. Observations of the lower stratosphere are improved through the use of special narrow and more transparent spectral channels. The instrument is programmable; thus, a variety of observation modes can be used, and may be adapted in flight to observe unexpected geophysical events. ☆

Key HIRDLS Facts:

- **Joint program between Oxford University and NCAR; Phase C/D initiated by the former September 1991, and postponed by the latter until 1995**
- **Prime Contractors: LORAL (U.S.) and Matra-Marconi Space (U.K.)**

For Further Information:
Gille, J. and J. Barnett, The High-Resolution Dynamics Limb Sounder (HIRDLS), in *The Use of EOS to Study Atmospheric Physics*, North Holland, 1992.

HIRDLS Parameters

Measurement Approach
Scanning infrared limb sounder
21 photoconductive HgCdTe detectors cooled to 80K
Each detector has a separate band pass interference filter

Swath: Typically six profiles across 2,000- to 3,000-km-wide swath
Spatial resolution: Profile spacing 400 x 400 km horizontally (equivalent to 4° long x 4° lat) x 1 km vertically; averaging volume for each data sample 1 km vertical x 10 km across x 400 km along line-of-sight

Accommodation Issues
Mass: 150 kg
Duty cycle: 100%
Power: 180 W (average), 230 W (peak)

Data rate: 40 kbps
Thermal control by: Paired 80K Stirling cycle coolers, central thermal bus, heaters, sun baffle
Thermal operating range: 20-30°C
FOV (scan range): Elevation, ±2.5° about -25.3° below horizontal; azimuth, -20° (sun side) to +50° (anti-sun side)
Detector IFOV: 1 km vertical x 10 km (2.5°) horizontal
Pointing requirements (platform+instrument, 3σ):
  Control: 900 arcsec (all axes)
  Knowledge: 250 arcsec (all axes)
  Stability: 30 arcsec/sec per axis
  Jitter: TBD
Physical size: 130 x 80 x 100 cm (stowed);
130 x 90 x 120 cm (deployed)

Co-Principal Investigators—John Barnett and John Gille

Dr. Barnett received an M.A. in Natural Sciences, with first class honors, from Cambridge University and a Ph.D. in Atmospheric Physics from Oxford University. He is currently a University Research Lecturer for the Department of Physics at Oxford. Dr. Barnett served as a member of data processing teams for the suite of Nimbus instruments, as Co-Investigator for Improved Stratospheric and Mesospheric Sounder (ISAMS), and as co-chairman of the COSPAR group on the Reference Middle Atmosphere. He is the recipient of the COSPAR William Nordberg Award and the Royal Meteorological Society L.F. Richardson Award.

John Gille received a B.S. in Physics, magna cum laude, from Yale University, an M.A. in Physics from Cambridge University, and a Ph.D. in Geophysics from MIT. Since 1977, he has served as Head of the Global Observations, Modeling, and Optical Techniques Section of NCAR. Dr. Gille was Co-Senior Scientist on LIMS, launched on Nimbus-7 in 1978, and was Principal Investigator on LRIR, which flew on Nimbus-6 in 1975. He has been involved in CLAES collaboration since 1982, with NOAA's development of GOMR, and on several investigations analyzing satellite data. He is a Fellow of the American Meteorological Society and the American Association for the Advancement of Science, and was the recipient of the NCAR Technology Advancement Award in 1978 and the NASA Exceptional Scientific Achievement Medal in 1982.

Co-Investigators

David Andrews, Clarendon Laboratory
Paul Bailey, National Center for Atmospheric Research
Byron Boville, National Center for Atmospheric Research
Guy Brasseur, National Center for Atmospheric Research
Michael Coffey, National Center for Atmospheric Research
Robert S. Harwood, University of Edinburgh
James R. Holton, University of Washington
Conway B. Leovy, University of Washington
William Mankin, National Center for Atmospheric Research
Michael E. McIntyre, University of Cambridge
Heinz G. Muller, University of Sheffield
Christopher T. Mutlow, Rutherford Appleton Laboratory
Alan O'Neill, British Meteorological Office
John A. Pyle, Cambridge University
Clive D. Rodgers, Oxford University
John Seeley, University of Reading
Frederic Taylor, Oxford University
Geraint Vaughan, University College of Wales
Robert J. Wells, Oxford University
John G. Whitney, Oxford University
E.J. Williamson, Oxford University

LIS

LIGHTNING IMAGING SENSOR

STARING TELESCOPE/FILTER IMAGING SYSTEM

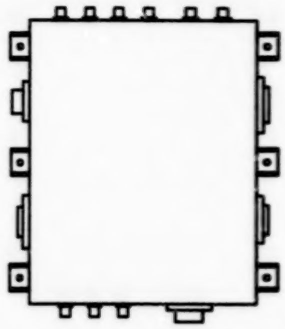
UNDER DEVELOPMENT FOR GEOSTATIONARY ORBIT;
FLOWN ON NASA AIRCRAFT

ACQUIRES AND INVESTIGATES THE DISTRIBUTION AND VARIABILITY OF LIGHTNING OVER THE EARTH

90% DETECTION EFFICIENCY UNDER BOTH DAY AND NIGHT CONDITIONS USING BACKGROUND REMOVER AND EVENT PROCESSOR

STORM-SCALE (5-KM) SPATIAL RESOLUTION;
2-MSEC TEMPORAL RESOLUTION

Sensor Head Assembly



Electronics Assembly

The calibrated optical LIS will investigate the global incidence of lightning, its correlation with rainfall, and its relationship with the global electric circuit. Conceptually, LIS is a simple device, consisting of a staring imager optimized to locate both intracloud and cloud-to-ground lightning with storm-scale resolution over a large region of the Earth's surface, to mark the time of occurrence, and to measure the radiant energy. It will monitor individual storms within the field-of-view (FOV) for 80 seconds, long enough to estimate the lightning flashing rate. Location of lightning flashes will be determined to within 5 km over a 600 x 600 km FOV.

The LIS design uses an expanded optics wide-FOV lens, combined with a narrow-band interference filter that focuses the image on a small, high-speed, charge-coupled device focal plane. The signal is read out from the focal plane into a real-time data processor for event detection and data compression. The particular characteristics of the sensor design result from the requirement to detect weak lightning signals during the day when the background illumination, produced by sunlight reflecting from the tops of clouds, is much brighter than the illumination produced by the lightning.

A combination of four methods is used to take advantage of the significant differences in the temporal, spatial, and spectral characteristics between the lightning signal and the background noise. First, spatial filtering is used to match the instantaneous FOV of each detector element in the LIS focal plane array to the typical cloud-top area illuminated by a lightning event (about 5 km). Second, spectral filtering is applied, using a narrow-band interference filter centered about the strong OI emission multiplet in the lightning spectrum at 777.4 nm. Third, temporal filtering is applied. The lightning pulse duration is of the order of 400 μsec, whereas the background illumination tends to be constant on a time scale of

Key LIS Facts:
- In-house MSFC development
- Phase C/D start January 1991
- EOS-funded instrument slated for launch on TRMM-1
- Under development for geostationary orbit

For Further Information:

Christian, H.J., R.J. Blakeslee, and S.J. Goodman, The Detection of Lightning from Geostationary Orbit, *Journal of Geophysical Research*, vol. 94, 13,329-13,337, 1989.

Christian, H.J., R.J. Blakeslee, and S.J. Goodman, Lightning Imaging Sensor (LIS) for the Earth Observing System, NASA Technical Memorandum 4350, MSFC, Huntsville, AL, February 1992.

seconds. The lightning signal-to-noise ratio improves as the integration time approaches the pulse duration. Accordingly, an integration time of 2 msec is chosen to minimize pulse splitting between successive frames and to maximize lightning detectability. Finally, a modified frame-to-frame background subtraction is used to remove the slowly varying background signal from the raw data coming off the LIS focal plane. If, after background removal, the signal for a given pixel exceeds a specified threshold, that pixel is considered to contain a lightning event.

LIS investigations will further understanding of processes related to, and underlying, lightning phenomena in the Earth/atmosphere system. These processes include the amount, distribution, and structure of deep convection on a global scale, and the coupling between atmospheric dynamics and energetics as related to the global distribution of lightning activity. The investigations will contribute to several important EOS mission objectives, including cloud characterization and hydrologic cycle studies. Lightning activity is closely coupled to storm convection, dynamics, and microphysics, and can be correlated to the global rates, amounts, and distribution of precipitation, to the release and transport of latent heat, and to the chemical cycles of carbon, sulfur, and nitrogen. LIS standard products will be intensities, times of occurrence, and locations of lightning events. ☆

LIS Parameters

Measurement Approach

Staring imager that detects the rate, position, and radiant energy of lightning flashes
Spectral filter to image at 0.777 μm onto a 128 x 128 CCD array detector
Event processor to subtract out the bright background during daylight (instrument taking data day and night)

Swath: 600 x 600 km
Spatial resolution: 5 km

Accommodation Issues

Mass: 20 kg
Duty cycle: 100%
Power: 33 W
Data rate: 6 kbps
Thermal control by: Heater, radiator
Thermal operating range: 0-40°C
FOV: 80° x 80°
Instrument IFOV: 0.7°
Pointing requirements (platform+instrument, 3σ):
  Control: None
  Knowledge: 1 km on ground
  Stability: TBD
  Jitter: TBD
Physical size:
  Sensor head assembly (cylindrical)—20 x 30 cm;
  Electronics assembly—30 x 20 x 30 cm

Principal Investigator—Hugh Christian

Hugh Christian is a graduate of the University of Alaska, and received an M.S. and Ph.D. in Space Physics and Astronomy from Rice University. He has served in various government, private industry, and academic capacities, primarily within his area of expertise: Thunderstorms, atmospheric electricity, lightning data acquisition systems, and airborne instrumentation. Since 1980, Dr. Christian has been a Space Scientist at the Marshall Space Flight Center.

Co-Investigators

Richard Blakeslee, Marshall Space Flight Center
Steven J. Goodman, Marshall Space Flight Center
Douglas M. Mach, University of Alabama

MIMR

MULTIFREQUENCY IMAGING MICROWAVE RADIOMETER

HIGH-RESOLUTION MICROWAVE SPECTROMETER

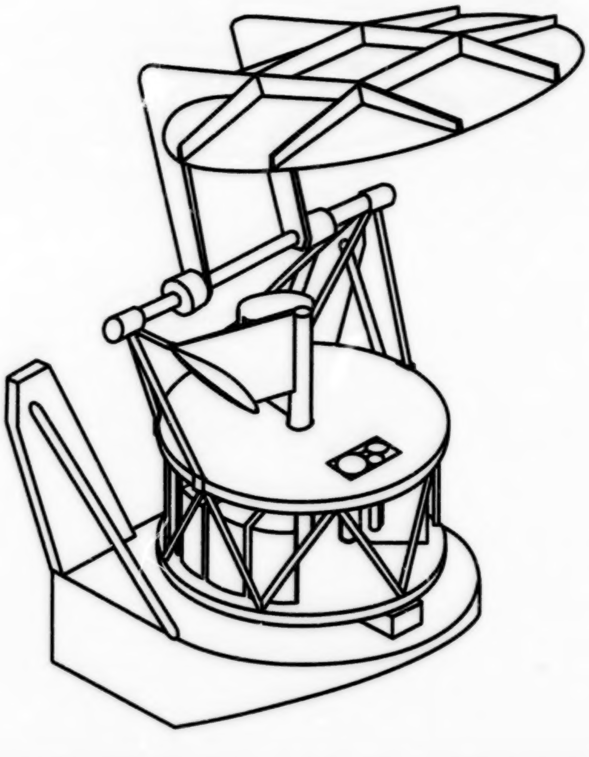
HERITAGE: SSM/I AND SMMR

MEASURES PRECIPITATION RATE, CLOUD WATER, WATER VAPOR, SEA SURFACE ROUGHNESS, SEA SURFACE TEMPERATURE, ICE, SNOW, AND SOIL MOISTURE

FREQUENCIES BETWEEN 6.8 AND 90 GHz

EXTERNAL CALIBRATION

1.6-M PARABOLIC ANTENNA AND ROTATING DRUM AT ~26 RPM



MIMR is a passive microwave radiometer provided under a Memorandum of Understanding with the European Space Agency (ESA). The instrument builds upon the successful design of the Special Sensor Microwave/Imager (SSM/I), but provides greater frequency diversity, improved spatial resolution, increased swath width, and improved antenna performance—allowing complete global coverage in less than 3 days. MIMR will provide a 20 percent greater swath width than available with current passive microwave radiometers. Slated for the EOS-PM satellite series, the instrument will observe numerous atmospheric and oceanic parameters, including precipitation, soil moisture, global ice and snow cover, sea surface temperature and wind speed, atmospheric cloud water, and water vapor.

MIMR data will be used in conjunction with data from other EOS instruments. Over land, MIMR observations complement visible, infrared, and active microwave observations of vegetation status, biomass, and soil moisture, which are also important for evaporation and transpiration studies. Over snow- and ice-covered areas, passive microwave data will complement high-resolution data available on surface roughness from synthetic aperture radar, thermal data, and visible multispectral measurements responsive to grain size to support extraction of moisture equivalence. Over oceans, passive microwave data, in conjunction with scatterometer and meteorological sounder data, can be used in studies of heat exchange across the air-sea surface, which are strongly dependent on measurements of sea surface temperature, wind, and atmospheric humidity in the ocean boundary layer. MIMR also will provide data on atmospheric water content and precipitation, to be interpreted in combination with Advanced Microwave Sounding Unit (AMSU) and Microwave Humidity Sounder (MHS) data.

MIMR operates at six frequencies, each with horizontal and vertical polarization: 6.8, 10.65, 18.7, 23.8, 36.5, and 90 GHz. MIMR

Key MIMR Facts:

- Phase C/D start expected early 1993, but may be delayed until 1995
- Phase B Contractor: Alenia
- Responsible Center: GSFC

For Further Information:

European Space Agency, MIMR Instrument Panel Report, Publication #SP-1138, Paris CEDEX 15, France.

employs nine feedhorns, yielding 20 available channels. The frequencies were chosen to maximize sensitivity to particular parameters of interest and to operate in protected regions of the spectrum. MIMR is designed to have a cross-track swath of 1,400 km at an incidence angle of 50°, which provides a 3-day global coverage of the Earth. At high latitudes (i.e., >45°), the overlap between consecutive swaths increases and daily coverage is provided. MIMR data products will include measurements in its 20 channels covering dual polarization from 6.8 to 90 GHz with corresponding 60- to 5-km resolution, 1 to 1.5K accuracy, and 0.2 to 0.7K radiometric stability. Channels will be converted to daily spectral maps on a 1° grid; monthly average maps on 1° grids will be produced for precipitation index, sea surface temperature, snow cover parameters, sea ice parameters, atmospheric water vapor burden over oceans, atmospheric cloud water burden over oceans, ocean surface wind stress, and soil moisture index. ☆

MIMR Parameters

Measurement Approach

Passive microwave radiometer
Retrieval of atmosphere, ocean, cryosphere, and land parameters
Multiple feedhorns (9) to cover bands from 6.8 to 90 GHz
0.2 to 0.7K radiometric stability
Minimum 1.6-m reflector
1 to 1.5K accuracy

Swath: 1,400 km
Spatial resolution: 4.86 km (90 GHz), 11.62 km (36.5 GHz), 22.3 km (23.8 GHz), 22.3 km (18.7 GHz), 38.6 km (10.65 GHz), 60.3 km (6.8 GHz)

Accommodation Issues

Mass: 223 kg
Duty cycle: 100%
Power: 171.4 W (average), 200 W (peak)
Data rate: 67 kbps
Thermal control by: Radiator
Thermal operating range: -10-50°C
FOV: Forward-looking conical scan
Instrument IFOV: ±60° cross-track
Pointing requirements (platform+instrument, 3σ):
  Control: 720 arcsec
  Knowledge: 108 arcsec
  Stability: 36 arcsec/sec
  Jitter: TBD
Physical size: 180 x 170 x 130 cm (stowed); 300 x 170 x 170 cm (deployed)
Antenna rotates at approximately 26 rpm

U.S. Team Leader—Roy W. Spencer (pending negotiation with ESA)

Roy W. Spencer received a B.S. in Atmospheric Science from the University of Michigan, and both an M.S. and Ph.D. in Meteorology from the University of Wisconsin. Currently, Dr. Spencer is a Space Scientist at the Marshall Space Flight Center, where he directs a program of satellite passive microwave research focusing on the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I), the Nimbus-7 Scanning Multispectral Microwave Radiometer (SMMR), and the TIROS-N Microwave Sounding Unit (MSU); and the development and flight of a high-altitude aircraft five-frequency scanning microwave radiometer. Dr. Spencer has been a member of several NASA-sponsored committees, including the Tropical Rainfall Measuring Mission (TRMM) Science Steering Group, the Earth Science Geostationary Platform Committee, and the Earth System Science Subcommittee on Winds and Precipitation.

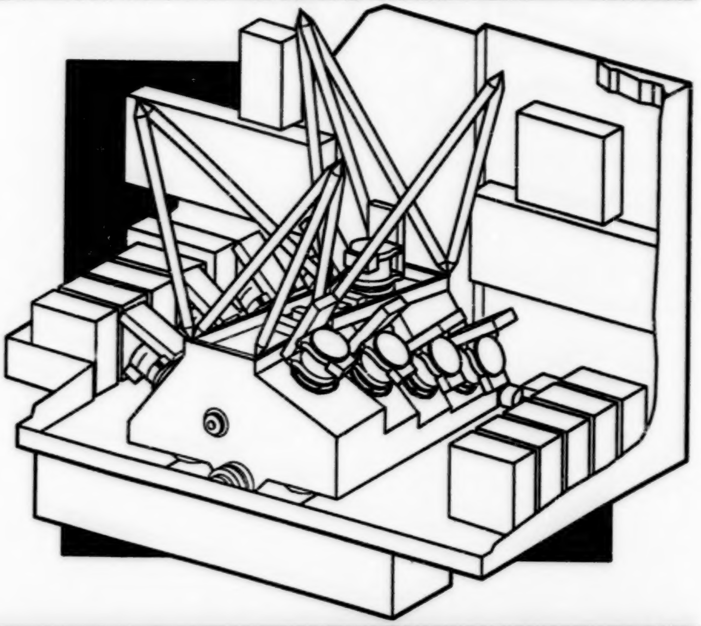
Team Members (pending negotiation with ESA)

Although Roy Spencer has been proposed as U.S. Team Leader, his acceptance as well as other U.S. Team Members is pending negotiation with ESA. Agreement on team composition awaits the Announcement of Opportunity (AO) process, with the following candidates to serve as the U.S. members of the MIMR science team.

Robert Adler, Goddard Space Flight Center
John Alishouse, NOAA/NESDIS
Don Cavalieri, Goddard Space Flight Center
Joseph Comiso, Goddard Space Flight Center
James Shiue, Goddard Space Flight Center
Thomas Wilheit, Texas A&M University

MISR

Multi-angle Imaging SpectroRadiometer



HERITAGE: GLL, WIDE-FIELD/PLANETARY CAMERA

PROVIDES TOP-OF-ATMOSPHERE, CLOUD, AND SURFACE ANGULAR REFLECTANCE FUNCTIONS

PROVIDES GLOBAL MAPS OF PLANETARY AND SURFACE ALBEDO, AND AEROSOL AND VEGETATION PROPERTIES

MISR is the only EOS instrument that will routinely provide multi-angle, continuous coverage of the Earth with high spatial resolution. The instrument will obtain multidirectional observations of each scene within a time scale of minutes, thereby under virtually the same atmospheric conditions. MISR uses nine separate charged coupled device (CCD)-based pushbroom cameras to observe the Earth at nine discrete view angles: One at nadir, plus four other symmetrical fore-aft views up to ±70.5° forward and aftward of nadir. Images at each angle will be obtained in four spectral bands centered at 0.443, 0.555, 0.67, and 0.865 µm. Each of the 36 instrument data channels (i.e., four spectral bands for each of the nine cameras) is individually commandable to provide ground sampling of 240 m, 480 m, 960 m, or 1.92 km. The swath width of the MISR imaging data is 356 km, providing multi-angle coverage of the entire Earth in 9 days at the equator and 2 days at the poles.

MISR images will be acquired in two observing modes: Global and Local. Global Mode provides continuous planet-wide observations, with most channels operating at moderate resolution and selected channels operating at the highest resolution for cloud screening, image navigation, and stereo-photogrammetry. Local Mode provides data at the highest resolution in all spectral bands and all cameras for selected 300 x 300 km regions.

MISR will be used to monitor global and regional trends in radiatively important optical properties (i.e., opacity, single scattering albedo, and scattering phase function) of natural and anthropogenic aerosols, including those arising from industrial and volcanic emissions, slash-and-burn agriculture, and desertification, and to determine their effect on solar radiation budget. Over land, the dependence of absolute radiance and scene contrast as a function of angle will be used to retrieve opacity, absorptivity, and phase function. Over ocean, the shape of the observed phase functions will provide constraints on the physical properties of the scattering particles. The reliance on angular signatures makes such techniques unavailable to nadir imagers. Aerosol information derived from MISR and radiative transfer algorithms developed as part of the MISR investigation will also be used to assist in the atmospheric correction of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and Moderate-Resolution Imaging Spectroradiometer (MODIS) data.

Multi-angle radiances obtained by MISR will be classified by scene type. The measured radiances will be directly integrated to yield estimates of reflected flux, hence albedo. In some cases, physical radiative transfer models will be used to improve the accuracy of the integrations. For determinations of these quantities at the surface, radiative transfer inversions of the top-of-atmosphere radiances will be used to retrieve multi-angle surface reflectances, using aerosol information also derived from MISR data. Automated stereo image matching algorithms will be used to derive surface topography and cloud elevations from multi-angle stereoscopic observations. Over cloud fields, the multi-angle radiometric and photogrammetric measurements will be used to investigate how spatial and seasonal variations of different cloud types affect the planetary solar radiation budget, and to develop cloud radiative parameterizations for representing heterogeneous cloud systems in general circulation models. Over the land surface, these data will aid studies of the impact of land surface processes on climate variables. Bidirectional reflectance distribution function (BRDF) measurements of various scene types will be used for the development and validation of models relating soil, snow, and ice angular reflectances to surface albedo. For vegetated terrain, measured angular signatures will be related to canopy structural parameters, will provide improved vegetation cover classifications, and will be used to retrieve surface hemispherical albedos. This information will be used to derive absorbed photosynthetically active radiation and improved measurements of vegetation canopy photosynthesis and transpiration rates. In contrast to single-view direction imagers, MISR data will be used to derive a vegetation index based on red and near-infrared fluxes, rather than radiances. The multi-angle observations will also provide information necessary to interpret directional vegetation indices acquired by wide-range angle scanners, such as MODIS.

MISR will also be able to supplement EOS studies of the biogeochemical cycle within the Earth's aquatic systems. Ocean phytoplankton pigment concentration will be derived using algorithms similar to those envisioned for MODIS. The concentration is estimated by forming the ratio of the water-leaving radiances at 0.443 and 0.555 μm.
MISR images will be radiometrically calibrated using monthly in-flight observations of deployable solar diffuser panels. The reflectance stability of the panels will be monitored using an array of radiation-resistant and quantum-efficient diodes. Semi-annual field calibration exercises are planned to provide ground-truth calibration of the diodes. Standard MISR data products will include calibrated images in Global and Local Modes, and several other data products as delineated below:

- Multi-angle bidirectional reflectance data for various types of cloud and surface covers with 1 to 2 percent angle-to-angle relative accuracy mapped onto 2-km grids
- Global maps of spectral planetary and surface hemispherical albedo with accuracies of ±0.03 on 2-km grids
- Retrieved aerosol opacities over land and ocean with accuracies of ±0.05 or 10 percent, whichever is larger, as well as other scattering properties, mapped onto 16-km grids. ☆

Key MISR Facts:
- **In-house JPL development**
- **Phase C/D start January 1991**

For Further Information:
Diner, D.J. et al., A Multi-angle Imaging SpectroRadiometer for Terrestrial Remote Sensing from the Earth Observing System, *International Journal of Imaging Systems and Technology*, **3, 92-107, 1991.**

MISR Parameters

Measurement Approach
Nine CCD cameras fixed at nine viewing angles out to ±70.5° forward and aft of nadir, including nadir
Four spectral bands discriminated via filters bonded to the CCDs
Global coverage in 9 days
0.03 hemispherical albedo accuracy
Larger of 0.05 or 10% aerosol opacity accuracy
1-2% angle-to-angle accuracy in bidirectional reflectance

Swath: 370 km (nadir camera), 408 km (non-nadir camera)
Spatial sampling: 240 m, 480 m, 960 m, or 1.92 km
Best resolution: 250 m (nadir), 275 m (non-nadir)

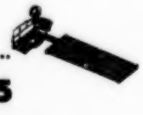
Accommodation Issues
Mass: 106 kg (including hard mount interface hardware)
Instrument duty cycle: 50%
Power: 67 W (average), 107 W (peak)
Heater Power: 14 W
Thermal control by: Passive cooling and active temperature stabilization
Thermal operating range: -20 to +40°C
FOV: ±59° down-track by ±15° cross-track
Data rate: 3.8 Mbps (average), 6.5 Mbps (peak)
Pointing requirements (spacecraft):
  Control: 240 arcsec
  Knowledge: 108 arcsec
  Stability: 7 arcsec per sec, 16 arcsec per 420 sec
Physical size: 127 x 78 x 92 cm

Principal Investigator—David J. Diner

David J. Diner received a B.S. in Physics with honors from the State University of New York at Stony Brook, and an M.S. and Ph.D. in Planetary Science from the California Institute of Technology. He joined the Jet Propulsion Laboratory as a National Research Council Resident Research Associate in 1978, and is currently a Technical Group Supervisor in the Atmospheric and Cometary Sciences Section. He has been involved in numerous NASA planetary and Earth remote-sensing investigations, as Principal and Co-Investigator. He is also a member of the American Astronomical Society Division for Planetary Sciences.

Co-Investigators

Thomas P. Ackerman, Pennsylvania State University
Carol J. Bruegge, Jet Propulsion Laboratory
Roger Davies, McGill University
Siegfried Gerstl, Los Alamos National Laboratory
Howard R. Gordon, University of Miami
John V. Martonchik, Jet Propulsion Laboratory
Jan-Peter Muller, University College London
Piers Sellers, Goddard Space Flight Center

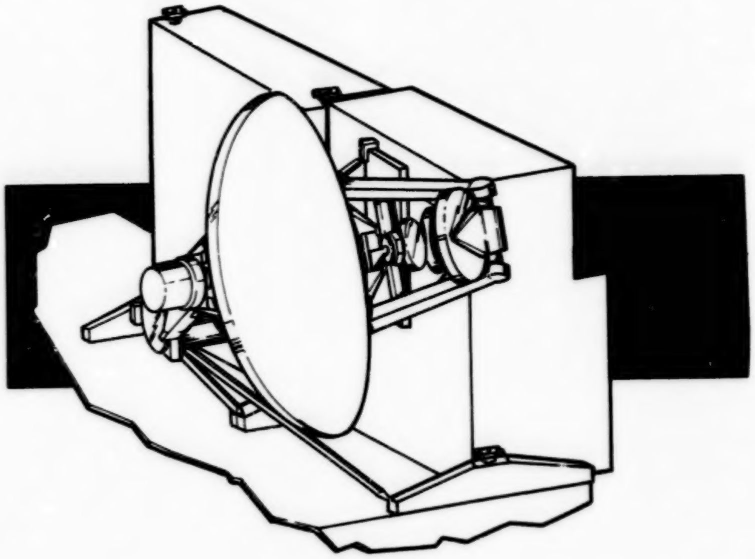


Selected for Flight on EOS-CHEM Series

MLS

MICROWAVE

LIMB SOUNDER



PASSIVE RADIATIONALLY COOLED MICROWAVE LIMB-SOUNDING RADIOMETER/SPECTROMETER

HERITAGE: UARS MLS

MEASURES THERMAL EMISSION FROM THE ATMOSPHERIC LIMB

SPECTRAL BANDS CENTERED AT 215, 440, AND 640 GHz AND 2.5 THz

SPECTRAL RESOLUTION: 1 MHz

INSTANTANEOUS FIELD-OF-VIEW AT 640 GHz AND HIGHER FREQUENCIES: 1.2 KM VERTICAL x 3 KM CROSS-TRACK x 300 KM ALONG-TRACK AT THE LIMB TANGENT POINT

The scientific priorities and objectives of the MLS investigation are to study and monitor the following processes and parameters vital to global change research:

- Chemistry of the lower stratosphere and upper troposphere—MLS measures lower stratospheric temperature and concentrations of H_2O, O_3, ClO, HCl, OH, HNO_3, NO, N_2O, HF, and CO for their effects on (and diagnoses of) transformations of greenhouse gases, radiative forcing of climate change, and ozone depletion. MLS measures upper tropospheric H_2O and O_3 for their effects on radiative forcing of climate change and diagnoses of exchange between the troposphere and stratosphere.
- Chemistry of the middle and upper stratosphere—MLS monitors ozone chemistry by measuring radicals, reservoirs, and source gases in all the chemical cycles now thought significant. Certain isotopic and excited states will also be measured to provide additional insight into stratospheric chemistry.
- The effect of volcanoes on global change—MLS measures SO_2, and other gases mentioned above, in volcanic plumes to investigate the effects of volcanic injections into the atmosphere.

A very important contribution to the EOS Program is that MLS measurements are not degraded in regions containing ice clouds (including polar stratospheric clouds) or aerosols. This is significant because phenomena affecting global change (e.g., water vapor distribution near the tropopause and heterogeneous chemistry) occur in these very regions. MLS contains an infrared radiometer that allows detection of clouds and aerosols; in conjunction with the millimeter/submillimeter radiometers, these data will provide information on water in all its physical phases (i.e., gaseous, liquid, solid).

Measurements are performed continuously, at all times of night and day, and can cover the altitude range from the upper troposphere to the lower thermosphere. The vertical scan is chosen to emphasize the lower stratosphere and upper troposphere, which are now of highest priority; however, the scan can be reprogrammed to emphasize other regions should priorities change. Complete latitude coverage is obtained each orbit. Pressure (from O_2 lines) and height (from a gyroscope measuring small changes in the field-of-view direction) are measured to provide accurate vertical information for the composition measurements.

Selected for Flight on EOS-CHEM Series

The EOS version of this instrument continues the successful international effort started on the Upper Atmosphere Research Satellite (UARS) MLS. The heterodyne radiometer systems used by MLS are capable of efficient measurement of atmospheric thermal emissions up to the frequencies of approximately 3 THz. Moreover, instrument modules can be easily changed (including additions and deletions) to accommodate evolving measurement priorities, resource availabilities, and technology advances. Radiational cooling provides excellent sensitivity so that mechanical coolers and/or cryogens are not required. MLS contains five heterodyne radiometers: The 215 GHz band is primarily to continue UARS MLS measurements of ClO and O_3, and to provide upper tropospheric H_2O and temperature; the 440 GHz band is primarily for stratospheric nitrogen chemistry; the 640 GHz band is primarily for stratospheric chlorine chemistry; the 1.2 THz band is primarily for HF; and the 2.5 THz band is primarily for OH. ☆

Key MLS Facts:

- In-house JPL development

For Further Information:

Waters, J.W. Submillimeter Wavelength Heterodyne Spectroscopy and Remote Sensing of Earth's Upper Atmosphere, *Proceedings of the IEEE: Special Issue on Terahertz Technology*, 1992.

Waters, J.W. Microwave Limb Sounding, chapter 8 in *Atmospheric Remote Sensing by Microwave Radiometry*, M. Janssen editor, Wiley & Sons, 1992.

MLS Parameters

Measurement Approach

Passive limb sounder measuring thermal emission
Spectral bands centered at 215 GHz, 440GHz, 640 GHz, and 2.5 THz

Spatial resolution: 3 x 300 km diameter horizontal x 1.2 km vertical

Accommodation Issues

Mass: 500 kg
Duty cycle: 100%
Power: 540 W
Data rate: 5 kbps
Thermal control: Via louvres to space or cold plate

Thermal operating range: 10-35°C
FOV: Boresight 62-74° relative to nadir
Instrument IFOV: ±2.5° (half-cone, along-track)
Pointing requirements (platform+instrument, 3σ):
  Control: 1,800 arcsec
  Knowledge: 180 arcsec
  Stability: 10 arcsec per 0.5 sec, 100 arcsec per 30 sec
  Jitter: TBD
Physical size: 160 x 80 cm (parabolic antenna);
160 x 180 x 160 cm (first add'l module);
150 x 60 x 130 cm (second add'l module)

Principal Investigator—Joe W. Waters

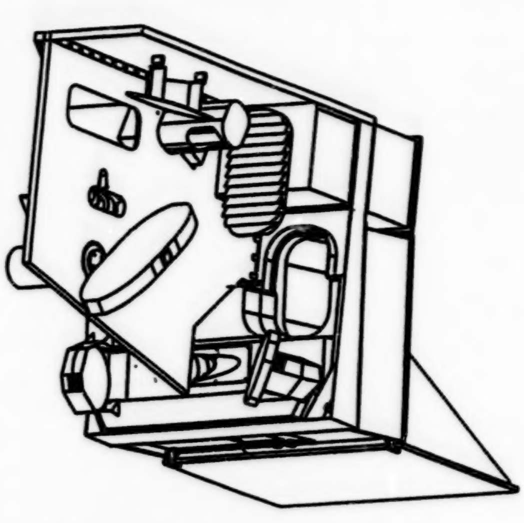
Dr. Waters has led the development of microwave limb sounding since its inception in 1974. His Ph.D. from the Massachusetts Institute of Technology (MIT) focused on microwave sensing of the upper atmosphere. Afterwards he was on the MIT research staff as a Co-Investigator on Nimbus microwave experiments. He moved on to the Jet Propulsion Laboratory (JPL) in 1973, and has been Principal Investigator on aircraft, balloon, and Upper Atmosphere Research Satellite (UARS) microwave limb sounding experiments. He is currently a senior research scientist at JPL, and group supervisor for the Microwave Atmospheric Science and Upper Atmosphere Experiment Development groups.

Co-Investigators

Richard E. Cofield, Jet Propulsion Laboratory
Lucien Froidevaux, Jet Propulsion Laboratory
Robert S. Harwood, University of Edinburgh
Robert F. Jarnot, Jet Propulsion Laboratory
Brian J. Kerridge, Rutherford Appleton Laboratory
David N. Matheson, Rutherford Appleton Laboratory
Gordon E. Peckham, Heriot-Watt University
William G. Read, Jet Propulsion Laboratory
Peter H. Siegel, Jet Propulsion Laboratory
William J. Wilson, Jet Propulsion Laboratory

MODIS

MODERATE-RESOLUTION IMAGING SPECTRORADIOMETER



MEDIUM-RESOLUTION, CROSS-TRACK, MULTISPECTRAL SCANNING RADIOMETER

HERITAGE: AVHRR, HIRS, LANDSAT TM, AND NIMBUS-7 CZCS

MEASURES BIOLOGICAL AND PHYSICAL PROCESSES

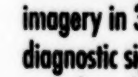
MODIS is an EOS facility instrument designed to measure biological and physical processes on a global basis every 1 to 2 days. Slated for both the EOS-AM and -PM satellite series, the instrument will provide long-term observations from which to derive an enhanced knowledge of global dynamics and processes occurring on the surface of the Earth and in the lower atmosphere. This truly multidisciplinary instrument will yield simultaneous, congruent observations of high-priority atmospheric (cloud cover and associated properties), oceanic (sea surface temperature and chlorophyll), and land surface features (land cover changes, land surface temperature, and vegetation properties). The instrument is expected to make major contributions to understanding of the global Earth system, including interactions between land, ocean, and atmospheric processes.

The MODIS instrument employs a conventional imaging radiometer concept, consisting of a cross-track scan mirror and collecting optics, and a set of linear detector arrays with spectral interference filters located in four focal planes. The optical arrangement will provide imagery in 36 discrete bands between 0.4 and 15 μm selected for diagnostic significance in Earth science. The spectral bands will have spatial resolution of 250 m, 500 m, or 1 km at nadir; signal-to-noise ratio of greater than 500 at 1-km resolution (at a solar zenith angle of 70°); and absolute irradiance accuracy of ±5 percent from 0.4 to 3 μm (2% relative to the sun) and 1 percent or better in the thermal infrared (3 to 15 μm). Each MODIS will provide daylight reflection and day/night emission spectral imaging of any point on the Earth at least every 2 days, with continuous duty cycle.

MODIS will provide specific global survey data products, which include the following:

- Surface temperature with 1-km resolution, day and night, with absolute accuracy of 0.2K for oceans and 1K for land
- Ocean color, defined as ocean-leaving spectral radiance within 5 percent from 415 to 653 nm, based on adequate atmospheric correction from near-infrared sensor channels
- Chlorophyll fluorescence within 50 percent at surface water concentrations of 0.5 mg/m^{-3}
- Concentration of chlorophyll *a* within 35 percent
- Vegetation/land surface cover, conditions, and productivity
  - Net primary productivity, leaf area index, and intercepted photosynthetically active radiation
  - Land cover type, with change detection and identification
  - Vegetation indices corrected for atmosphere, soil, and directional effects
  - Snow cover and reflectance
- Cloud cover with 250-m resolution by day and 1,000-m resolution at night
- Cloud properties characterized by cloud droplet phase, optical thickness, droplet size, cloud-top pressure, and emissivity
- Aerosol properties defined as optical thickness, particle size, and mass transport
- Fire occurrence, size, and temperature
- Global distribution of total precipitable water.

MODIS will fly on both the EOS-AM and -PM satellites to maximize cloud-free remote sensing of the Earth's surface and to exploit synergism with other EOS sensors. ☆



MODIS Parameters

Measurement Approach
36 spectral bands—20 within 0.4-3.0 μm; 16 within 3-15 μm
Continuous global coverage every 1 to 2 days
Polarization sensitivity is less than 2% for the visible out to 2.2 μm
Signal-to-noise ratio 830:1 (443 nm), 745:1 (520 nm), and 503:1 (865 nm)
Absolute irradiance accuracy of 5% for <3 μm and 1% for >3 μm
Absolute temperature accuracy 0.2K for oceans and 1K for land
Daylight reflection and day/night emission spectral imaging

Swath: 2,300 km at 110° (±55°)

Accommodation Issues
Mass: 250 kg
Duty cycle: 100%
Power: 225 W (average), 275 W (peak)
Data rate: 6.2 Mbps (average), 11 Mbps (day), 2.5 Mbps (night)
Thermal control by: Radiator
Thermal operating range: TBD
Instrument IFOV: 250 m (2 bands), 500 m (5 bands), 1,000 m (29 bands)
FOV: ±55° cross-track

Pointing requirements (platform+instrument, 3σ):
Control: 3,600 arcsec
Knowledge: 141 arcsec
Stability: 28 arcsec/sec
Jitter: 1,031 arcsec/sec (yaw and roll), 47 arcsec/sec (pitch)
Physical size: 95.2 x 158.3 x 133.6 cm (stowed)

Key MODIS Facts:
- Phase C/D start August 1991
- Prime Contractor: Santa Barbara Research Center
- Responsible Center: GSFC

For Further Information:

Salomonson, V.V. and D.L. Toll, The Moderate Resolution Imaging Spectrometer-Nadir (MODIS-N) Facility Instrument, *Advances in Space Research*, vol. 11(3), 231-236, 1991.

King, M.D., Y.J. Kaufman, W.P. Menzel, and D. Tanré, Remote Sensing of Cloud, Aerosol, and Water Vapor Properties from MODIS, *IEEE Transactions in Geoscience and Remote Sensing*, vol. 30(1), 2-27, 1992.

Team Leader—Vincent Salomonson

Vincent Salomonson has over 25 years of experience in the fields of meteorology, agricultural engineering, atmospheric science, and hydrology. He was awarded a Ph.D. in Atmospheric Science from Colorado State University in 1968, the year he joined Goddard Space Flight Center (GSFC). He was recently appointed Director of Earth Sciences at GSFC.

Dr. Salomonson brings substantial experience to his role as Team Leader of MODIS. He has functioned informally and formally as the MODIS Team Leader for the past 5 years. He also served for 12 years as the Landsat-4,5 Project Scientist, including the leadership and management of the Landsat Image Data Quality and Analysis (LIDQA) Investigator Team and Thematic Mapper research in the Earth Sciences Investigator Team. Additional experience includes over 17 years as a line manager of research groups at GSFC and the leadership of the NASA Water Resources Subdiscipline Panel and Program for several years in the 1970s. He has published research materials directly relevant to the investigation, and has over 100 refereed publications, conference proceedings, and NASA reports to his credit.

Cited on numerous occasions for his outstanding research and scientific achievement, Dr. Salomonson is the recipient of eight NASA awards for exceptional achievement, service, and performance; the Distinguished Achievement Award of the IEEE Geoscience and Remote Sensing Society; the William T. Pecora Award; and the Distinguished Alumnus Award from Colorado State University. In addition to his present duties at Goddard, he recently served as the President of the American Society for Photogrammetry and Remote Sensing.

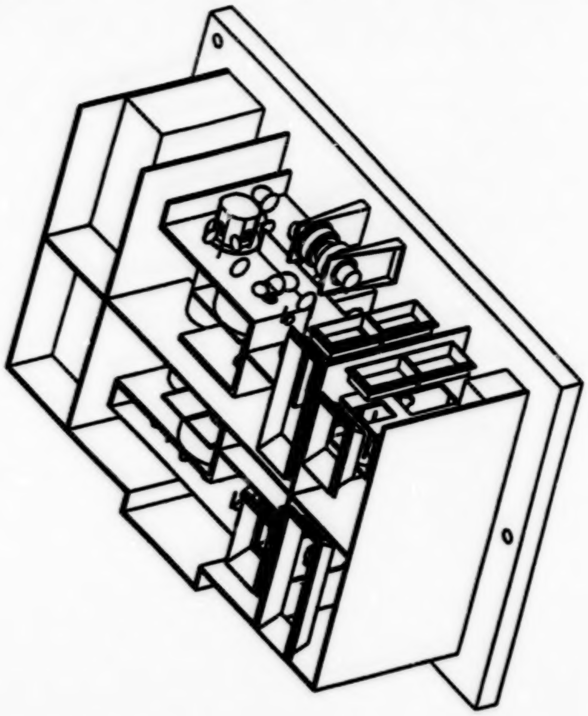
Team Members

Mark R. Abbott, Oregon State University
William Barnes, Goddard Space Flight Center
Ian Barton, CSIRO
Otis B. Brown, University of Miami
Kendall L. Carder, University of South Florida
Dennis K. Clark, NOAA/National Environmental Satellite, Data, and Information Service
Wayne Esaias, Goddard Space Flight Center
Robert H. Evans, University of Miami
Howard R. Gordon, University of Miami
Frank E. Hoge, Wallops Flight Facility
Alfredo R. Huete, University of Arizona
Christopher O. Justice, Goddard Space Flight Center
Yoram J. Kaufman, Goddard Space Flight Center
Michael D. King, Goddard Space Flight Center
W. Paul Menzel, NOAA/University of Wisconsin–Madison
Jan-Peter Muller, University College London
John Parslow, CSIRO
Steven W. Running, University of Montana
Philip N. Slater, University of Arizona
Alan H. Strahler, Boston University
Didier Tanre, CNRS/Laboratoire d'Optique Atmospherique
Vern Vanderbilt, Ames Research Center
Zhengming Wan, University of California–Santa Barbara

Selected for Flight on EOS-AM1

MOPITT

MEASUREMENTS OF POLLUTION IN THE TROPOSPHERE



FOUR-CHANNEL CORRELATION SPECTROMETER WITH CROSS-TRACK SCANNING

HERITAGE: PRESSURE-MODULATED CELL ELEMENTS USED IN THE PMR, SAMS, AND ISAMS INSTRUMENTS, USING SIMILAR CORRELATION SPECTROSCOPY TECHNIQUES

MEASURES UPWELLING RADIANCE AT 2.3, 2.4, AND 4.7 μM

USES PRESSURE MODULATION AND LENGTH MODULATION CELLS TO OBTAIN CO CONCENTRATIONS IN 3-KM LAYERS AND CH_4 COLUMN

The MOPITT experiment is provided under a Memorandum of Understanding with the Canadian Space Agency (CSA). MOPITT will measure emitted and reflected infrared radiance in the atmospheric column, which, when analyzed, permits retrieval of tropospheric CO profiles and total column CH_4.

Both CO and CH_4 are produced by biomass systems, oceans, and human activities. CO is intimately connected with the OH chemical cycle in the troposphere, and moves both vertically and horizontally within the troposphere. CH_4 is a greenhouse gas and is increasing on an annual basis. MOPITT measurements will permit studies of the global and temporal distributions that drive budget and source/sink studies. Since the human species has a significant influence on both CO and CH_4 concentrations, a better understanding of the role of these constituents is essential in understanding anthropogenic effects on the environment.

MOPITT operates on the principle of correlation spectroscopy (i.e., spectral selection of radiation emission or absorption by a gas using a sample of the same gas as a filter). The instrument modulates sample gas density by changing the length or the pressure of the gas sample in the optical path of the instrument. This modulation changes the absorption profile in the spectral lines of the gas in the cell as observed by a detector. Thus, the AC output of the detector, measured at the frequency that the gas sample is modulated, will be equal to the radiation detected if the gas cell and its modulator were replaced by an optical filter with a profile that exactly matches the absorption features of the sample gas in the modulator cell.

Atmospheric sounding and column CO are mapped by using thermal and reflected solar channels in the regions of 4.7 and 2.3 μm, respectively. Column CO and CH_4 are measured using solar channels viewed through modulation cells to sense solar radiation reflected from the surface. The solar channels are duplicated in the instrument at different correlation cell pressures, to allow a failure in one channel without compromising the column measurement.

Key MOPITT Facts:
- Flight on EOS-AM-2 to be confirmed
- Phase C/D start October 1992
- CSA to provide the instrument
- Prime Contractor: COM DEV

For Further Information:
Drummond., J.R., Measurements of Pollution in the Troposphere (MOPITT), in *The Use of EOS to Study Atmospheric Physics*, J. Gille and G. Visconti (ed.), North Holland, 1991.

MOPITT is designed as a scanning instrument. It has a field-of-view of 1.8°, which is equivalent to an approximately 22-km footprint at nadir. The instrument scan line consists of 29 pixels, each at 1.8° increments. The maximum scan angle is 26.1° off-axis, which is equivalent to a swath width of 640 km. This swath leaves gaps in coverage between successive orbits using the nominal 705-km altitude and 98.2° inclination orbit.

MOPITT data products will include gridded retrievals of CH_4 with a horizontal resolution of 22 km and a precision of 1 percent. Gridded CO soundings will be retrieved with 10 percent accuracy in three vertical layers between 0 and 15 km. These soundings will be taken at laterally scanned sampled locations with 22-km horizontal resolution. Column CO abundance will be retrieved and gridded with 22-km horizontal resolution. Scientific studies will employ these data to derive three-dimensional global maps as part of an effort to model global tropospheric chemistry. ☆

MOPITT Parameters

Measurement Approach

Correlation spectroscopy utilizing both pressure- and length-modulated gas cells, with detectors at 2.3, 2.4, and 4.7 µm
Measures vertical profile of CO and total column of CH_4
CO concentration accuracy is 10%
CH_4 column abundance accuracy is 1%

Swath: 616 km
Spatial resolution: 22 x 22 km

Accommodation Issues

Mass: 120 kg
Power: 200 W

Duty cycle: 100%
Data rate: 6 kbps
Thermal control by: 80K Stirling cycle cooler, central thermal bus
Thermal operating range: 25°C (instrument), 100K (detectors)
FOV: 22 x 638 km (scanned, 29 fields)
Instrument IFOV: 22 x 22 km (1.8 x 1.8°)
Pointing requirements (platform+instrument, 3σ):
  Control: 500 arcsec
  Knowledge: 500 arcsec
  Stability: 322 arcsec/12.47 sec
Physical size: 102.9 x 72.9 x 43.6 cm (stowed);
  102.9 x 75.1 x 43.6 m (deployed)

Principal Investigator—James Drummond

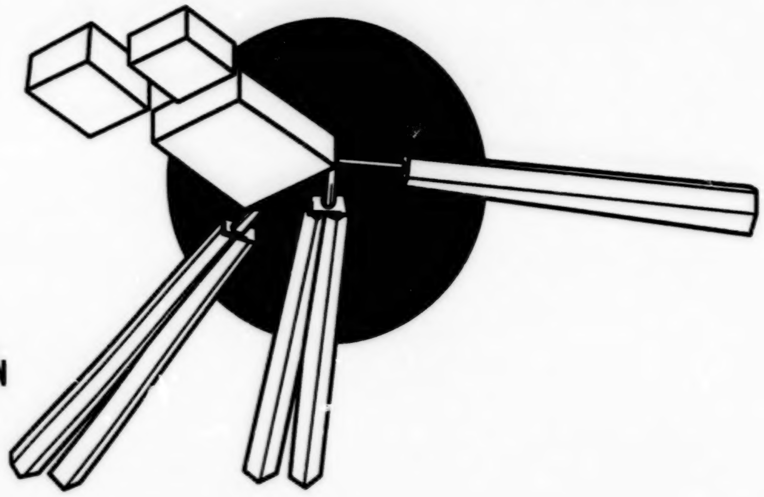
James Drummond has taught in the Physics Department at the University of Toronto since 1979, as Associate Professor since 1984. He studied at Oxford University where he obtained his B.A. and D.Phil. degrees in Physics. He was a Visiting Scientist in the Atmospheric Chemistry Division of the National Center for Atmospheric Research in 1987. His research interests are in the field of atmospheric measurements and modeling, and he has participated in several balloon and spacecraft experiments in said areas. Dr. Drummond has presented research papers at international meetings and symposia, and in refereed journals.

Co-Investigators

Guy Brasseur, National Center for Atmospheric Research
G.R. Davis, University of Saskatoon
John C. Gille, National Center for Atmospheric Research
Jack McConnell, York University
Guy Peskett, Oxford University
Henry G. Reichle, Langley Research Center
N. Roulet, York University

NSCAT II

NASA SCATTEROMETER II



SCATTEROMETER WITH SIX SLOTTED WAVEGUIDE Ku-BAND "STICK" FAN-BEAM ANTENNAS

HERITAGE: SEASAT, NSCAT

ONBOARD DIGITAL DOPPLER FILTERING FOR ALONG-BEAM RESOLUTION

ACQUIRES ALL-WEATHER MEASUREMENTS OF SURFACE WIND SPEED AND DIRECTION OVER THE GLOBAL OCEANS

NSCAT II is designed to acquire accurate, high-resolution, continuous, all-weather measurements of near-surface vector winds over the ice-free global oceans. As the only instrument capable of acquiring measurements of wind velocity—both speed and direction—under all-weather conditions, NSCAT II data are crucial for studies of tropospheric dynamics and air-sea momentum fluxes.

NSCAT II transmits pulses of microwave radiation at 14 GHz and measures the backscattered signal from the ocean. With knowledge of the range and instrument parameters such as antenna gain, the backscattered power data can be used to directly calculate the normalized radar cross section of the sea surface. At moderate incidence angles, the received power is primarily a result of Bragg scattering from centimetric ocean waves whose amplitudes and directional distributions are in approximate local equilibrium with the local wind; thus, the backscattered power will vary as a function of wind speed and wind direction relative to the radar beam. An empirically based geophysical model function relates the normalized radar cross section to wind speed and relative direction as a function of incidence angle, polarization, and frequency of the incident and backscattered radiation. Multiple measurements of the normalized radar cross section of the same area on the sea surface, but from different directions relative to the wind, are used to invert the model function to derive both wind speed and wind direction simultaneously.

NSCAT II uses a total of six slotted waveguide fan-beam antennas, three on each side, to acquire measurements in two continuous, 600-km wide swaths separated by a 325-km gap at nadir. All six antenna transmit and receive vertically polarized radiation; one antenna on each side also transmits/receives horizontal polarization. The multiple antennas are aligned at different azimuth angles to acquire the multi-directional data needed to invert the model function. Owing to spacecraft orbital velocity and Earth rotation, the backscattered power is doppler shifted as a function of spatial location. For NSCAT II, along-beam resolution is achieved using an onboard digital processor that Fourier transforms the received signal into 25-km resolution measurement cells.

Data products NSCAT II will consist of global multi-azimuth normalized radar cross section measurements; 25-km^2 resolution ocean vector winds (~12% speed and 20° direction accuracies for wind speeds of 3-50 m/sec) in each of the swaths; and spatially and temporally averaged wind field maps with 1° spatial resolution and 2-day temporal resolution. NSCAT II will measure vector winds over ~79% of the global oceans each day, with virtually complete coverage in every 2-day period. The wind velocity data from NSCAT II will be used for calculating all air-sea fluxes, for modeling upper ocean circulation and tropospheric dynamics, and for improving global weather predictions. ☆

NSCAT Follow-On Parameters

Measurement Approach

Active microwave radar at 13.995 GHz

Six fan-beam antennas used to determine radar scattering cross section and infer wind velocity over the ocean

All-weather capability

Wind speeds between 3-50 msec^{-1} accurate to 12%

Wind vector directions accurate to 20°

Swath: Two 600-km widths, separated by 325-km nadir gap

Spatial resolution: 25 x 25 km

Accommodation Issues

Mass: 270 kg

Power: 290 W

Duty cycle: 100%

Data rate: 5.1 kbps

Thermal control by: Central thermal bus

Thermal operating range: 5-50°C

FOV: Complex fan-beam from antennas, resulting in two 600-km-wide swaths separated by 325-km nadir data gap

Instrument IFOV: ±50° from each antenna

Pointing requirements (platform+instrument, 3σ):

Control:	324 arcsec
Knowledge:	216 arcsec
Stability:	396 arcsec per 1,800 sec
Jitter:	TBD

Physical size: 318 x 20 x 18 cm (antennas);
122 x 91 x 25 cm (RFS/REU);
84 x 48 x 25 cm (DSS);
38 x 48 x 25 cm (RES/DIU)

Requires spatially and temporally co-located multi-channel microwave radiometer measurements for rain correction

Key NSCAT II Facts:

- Follow-on to NSCAT, which will fly on ADEOS in 1996
- In-house JPL development, with subcontracts for RF subsystems
- Phase C/D start to be determined

For Further Information:

Naderi, F.M., M.H. Freilich, and D.G. Long, Spaceborne radar measurement of wind velocity over the ocean: An overview of the NSCAT scatterometer system, *Proceedings of the Institute for Electronics and Electrical Engineers*, June 1991.

Principal Investigator—Michael Freilich

Michael Freilich received degrees in Physics (honors) and Chemistry from Haverford College, and a Ph.D. in Oceanography from Scripps Institution of Oceanography in 1982. From 1982-83, he was an assistant professor at the Marine Sciences Research Center at the State University of New York. He joined the Jet Propulsion Laboratory in 1983, as a member of the Oceanography Group studying scatterometry and surface wave dynamics. Currently, he is a professor in the School of Oceanography and Atmospheric Sciences at Oregon State University. In addition, he is a Principal Investigator and Coordinating Investigator on the European Space Agency (ESA) European Remote Sensing Satellite-1 (ERS-1) Science Working Team and, since 1983, has been Project Scientist for the NSCAT Project. He chairs the NSCAT Science Working Team and is responsible for all science-related aspects of the NSCAT Project.

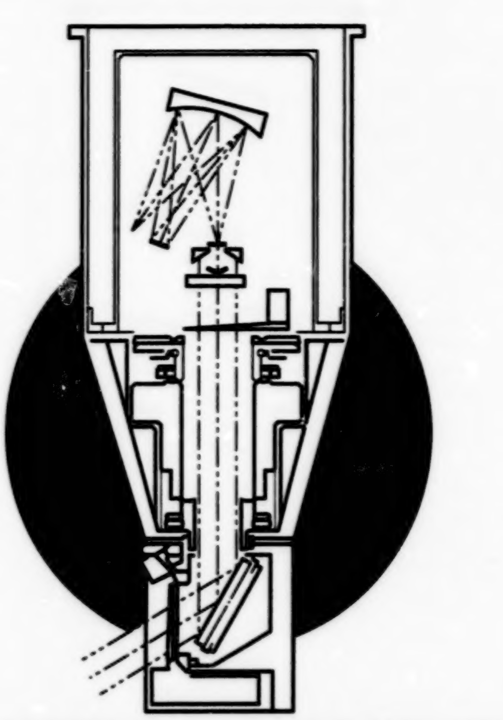
Co-Investigators

Robert M. Atlas, Goddard Space Flight Center
Robert A. Brown, University of Washington
Peter Cornillon, University of Rhode Island
David Halpern, Jet Propulsion Laboratory
Ross N. Hoffman, Atmospheric and Environmental Research
Fuk-Kwoh Li, Jet Propulsion Laboratory
W. Timothy Liu, Jet Propulsion Laboratory
Richard K. Moore, University of Kansas
James J. O'Brien, Florida State University

Selected for Flight on EOS-AERO and -CHEM Series

SAGE III

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III



EARTH LIMB-SCANNING GRATING SPECTROMETER

HERITAGE: SAM II, SAGE I, AND SAGE II

OBTAINS GLOBAL PROFILES OF AEROSOLS, O_3, H_2O, NO_2, NO_3, OClO, CLOUDS, TEMPERATURE, AND PRESSURE IN THE MESOSPHERE, STRATOSPHERE, AND TROPOSPHERE

1- TO 2-KM VERTICAL RESOLUTION

SAGE III is a natural and improved extension of the successful Stratospheric Aerosol Measurement II (SAM II), SAGE I, and SAGE II experiments. The additional wavelengths and lunar occultation that SAGE III provides will improve aerosol characterization; improve the gaseous retrievals of O_3, H_2O, and NO_2; add retrievals of NO_3 and OClO; extend the vertical range of measurements; and provide a totally self-calibrating instrument independent from any external data needed for retrieval. The instrument will accomplish the following science objectives:

- Retrieve global profiles (1- to 2-km vertical resolution) of atmospheric aerosols, ozone, water vapor, NO_2, NO_3, OClO, temperature, and pressure in the mesosphere, stratosphere, and troposphere
- Investigate the spatial and temporal variability of the measured species in order to determine their role in climatological processes, biogeochemical cycles, the hydrologic cycle, and atmospheric chemistry
- Characterize tropospheric and stratospheric aerosols and upper tropospheric and stratospheric clouds, and investigate their effects on the Earth's environment, including radiative, microphysical, and chemical interactions
- Extend the SAM II, SAGE I, and SAGE II self-calibrating solar occultation data sets (begun in 1978), enabling the detection of long-term trends
- Provide atmospheric data essential for the calibration and interpretation/correction of other satellite sensors, including EOS and ground-based sensors.

SAGE III takes advantage of both solar and lunar occultations to measure aerosol and gaseous constituents of the atmosphere. Most of the objectives rely on the solar occultation technique, which involves measuring the extinction of solar energy by aerosol and gaseous constituents in the spectral region from 0.29 to 1.55 μm during spacecraft sunrise and sunset events. For example, during a sunset event, exoatmospheric solar limb data are obtained when the sun-satellite vector is high above the Earth's atmosphere. As the sun sets, a series of scans through the atmosphere is performed during which measurements of the solar extinction by the atmosphere are made. Because all atmospheric measurements are ratioed to the exoatmospheric solar limb profiles taken during the same event, the

Key SAGE III Facts:

- EOS-AERO spacecraft to be provided by international partner
- Prime Contractor: Ball Aerospace
- Responsible Center: LaRC

For Further Information:

McCormick, M.P., SAGE III Capabilities and Global Change, in *29th Aerospace Sciences Meeting of the American Institute of Aeronautics and Astronautics*, Washington, D.C., 1991.

instrument is self-calibrating, and the retrieved data are not susceptible to long-term instrument degradation.

The moon will be used as another source of light for occultation measurements. In the spectral region from 0.4 to 0.95 µm, the moon has a relatively flat (i.e., grey) albedo. A determination of the average lunar spectral albedo is obtained by ratioing the exoatmospheric scans of the moon to an appropriate set of exoatmospheric scans of the sun, thereby ratioing out the structure in the solar spectrum. This average lunar spectral albedo can then be used along with the extinction cross sections of all absorbing species in an optimal fit to the measurements.

Present plans call for concurrent flight of two instruments—one in an inclined orbit (57°) and one in a sun-synchronous orbit—to obtain near-global coverage. This comprehensive approach will allow SAGE III to make long-term measurements and to provide the congruent aerosol and cloud data important to radiative and atmospheric chemistry studies. ☆

SAGE III Parameters

Measurement Approach

Self-calibrating solar and lunar occultation, with nine spectral channels (290-1,550 nm) to study aerosols, ozone, OClO, NO_2, NO_3, water vapor, temperature, and pressure

Swath: n/a (looks at sun and/or moon through Earth's limb)
Spatial resolution: 1-2 km vertical

Accommodation Issues

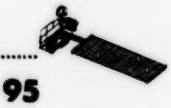
Mass: 40 kg
Duty cycle: During solar and lunar Earth occultation
Power: 15 W (average), 60 W (peak)
Data rate: 100 kbps for 8 min, three times per orbit
Thermal control by: Heaters and thermal electric cooler
Thermal operating range: 10-30°C
FOV: ±180° azimuth, 19 to 29° elevation
Instrument IFOV: <0.5 km vertical at 20-km tangent height
Pointing requirements (platform+instrument, 3σ):
  Control: 3600 arcsec/sec
  Knowledge: 900 arcsec/axis
  Stability: 30 arcsec/sec per axis
  Jitter: TBD
Physical size: 25 x 25 x 42 cm
34-cm diameter x 74 cm

Principal Investigator—M. Patrick McCormick

M. Patrick McCormick received an M.A. and Ph.D. in Physics from the College of William & Mary. He has been with NASA/Langley Research Center since 1967, and is presently Head of the Aerosol Research Branch. Dr. McCormick is Principal Investigator on SAM II, SAGE I, SAGE II, and LITE spaceflight experiments, as well as numerous other atmospheric remote-sensing instrument and data analysis experiments. He received the Arthur S. Flemming Award for Outstanding Young People in Federal Service in 1979, the NASA Exceptional Scientific Achievement Medal in 1981, the American Meteorological Society's Jule G. Charney Award in 1991, and numerous NASA Group or Special Achievement Awards. In addition, he received an Honorary Doctor of Science degree from the Washington & Jefferson College in 1981, and has served on their Board of Trustees. Dr. McCormick is a member of the International Radiation Commission, the American Meteorological Society, and the American Geophysical Union, and chairs the International Coordination Group on Laser Atmospheric Studies.

Co-Investigators

Barry Bodhaine, NOAA/Climate Monitoring and Diagnostics Laboratory
William P. Chu, Langley Research Center
Derek M. Cunnold, Georgia Institute of Technology
John Deluisi, NOAA/Environmental Research Laboratory
Philip A. Durkee, Naval Postgraduate School
Benjamin M. Herman, University of Arizona
Peter V. Hobbs, University of Washington
Geoffrey Kent, Science and Technology Corporation
Jacqueline Lenoble, Universite des Sciences et Techniques de Lille
Alvin J. Miller, NOAA/National Weather Service
Volker Mohnen, State University of New York
Venkatachalam Ramaswamy, Princeton University
David H. Rind, Goddard Institute for Space Studies
Philip B. Russell, Ames Research Center
Vinod K. Saxena, North Carolina State University
Eric Shettle, Naval Research Laboratory
Gabor Vali, University of Wyoming
Steven Wofsy, Harvard University
Joseph M. Zawodny, Langley Research Center

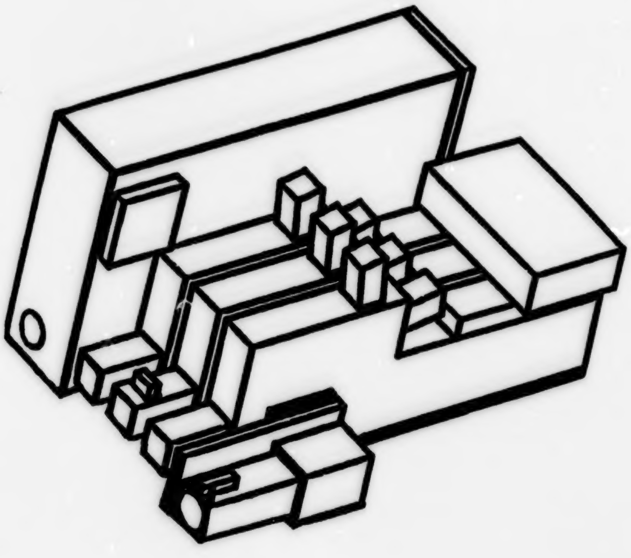


Selected for Flight on EOS-CHEM Series

SOLSTICE II

SOLAR STELLAR IRRADIANCE

COMPARISON EXPERIMENT II



FOUR-CHANNEL ULTRAVIOLET SPECTROMETER (TWO-AXIS SOLAR TRACK)

**COMPOSED OF AN ULTRAHIGH-RESOLUTION SPECTROMETER,
LOW-RESOLUTION SPECTROMETERS, AND
AN EXTREME ULTRAVIOLET PHOTOMETER**

HERITAGE: UARS SOLSTICE

RANGE OF 115 TO 440 nm

**THREE CHANNELS HAVE A SPECTRAL RESOLUTION OF
0.2 nm; THE FOURTH CHANNEL HAS A RESOLUTION OF 0.0015 nm**

**PROVIDES DAILY MEASUREMENT OF FULL-DISK SOLAR ULTRAVIOLET IRRADIANCE,
WITH CALIBRATION MAINTAINED BY COMPARISON TO BRIGHT, EARLY-TYPE STARS**

SOLSTICE II provides precise daily measurements of the full-disk solar ultraviolet (UV) irradiance between 5 and 440 nm. The sun's UV radiation is the dominant energy source to the Earth's atmosphere, where small changes in the radiation field have an important effect on atmospheric temperature, chemistry, structure, and dynamics. Moreover, even small alterations in the atmosphere (e.g., small changes in total ozone) can produce dramatic differences in the solar radiation reaching the Earth's surface. Measuring small changes in solar UV irradiance will improve understanding of corresponding changes in the photochemistry, dynamics, and energy balance of the middle atmosphere. Changes resulting from the 27-day solar rotation and the 11-year solar cycle will receive emphasis, as will those arising from solar flare incidents. SOLSTICE II will continue the UV observations initiated by its predecessor aboard the Upper Atmosphere Research Satellite (UARS).

The SOLSTICE II instrument consists of a five-channel spectrometer together with the required gimbal system to point the instrument at the sun and selected stars. The stellar targets, observed with the same optics and detectors as those directed at the sun, are essential for they determine the long-term drift correction to the SOLSTICE II calibration. The ensemble average flux from these 30 or so bright early-type stars should remain absolutely constant over arbitrarily long time periods. This unique method thereby establishes the instrument response as a function of time throughout the EOS mission and yields time series of solar variability that are completely corrected for instrumental drift.

The investigation will also model the penetration of solar radiation down into the Earth's atmosphere and establish the radiation field at all locations and altitudes, including the Earth's surface. In certain wavelength intervals, the depth of penetration varies dramatically due to details in the atmospheric absorption, and calculations require solar data with very high spectral resolution. To accommodate these measurements, a separate, high-resolution spectrometer channel is included. The standard SOLSTICE II data product will be a daily average of the solar UV irradiance from 5 to 440 nm. More specifically, data products will consist of solar UV irradiance from 30 to 440 nm, the solar UV irradiance from 115 to 320 nm at much higher resolution, and extreme UV irradiance between 5 and 20 nm. ☆

SOLSTICE II Parameters

Measurement Approach
Spectral range from 5-440 nm
Photometric accuracy better than 5% absolute (1% relative)
Spectral resolution: 0.2 nm and 0.0015 nm

Swath: n/a
Spatial resolution: n/a

Accommodation Issues
Mass: 99.5 kg
Duty cycle: 74% data taking
Power: 34 W (99% of time), 42 W (1% of time)
Data rate: 5 kbps (average), 8 kbps (peak)
Thermal control by: Passive radiator
Thermal operating range: 0-30°C (15° average)
FOV: 1.5°
Instrument IFOV: n/a

Pointing requirements (celestial pointer, 3σ):
Control: ±6 arcmin
Knowledge: 60 arcsec
Stability: 15 arcsec per 15 min
Jitter: 15 arcsec per sec
Physical size: 121 x 88 x 61 cm

Key SOLSTICE II Facts:
- Responsible Center: NCAR

For Further Information:
Rottman, G.J. and T.N. Woods, In-flight Calibration of Solar Irradiance Measurements by Direct Comparison with Stellar Observations, in *Recent Advances in Sensors, Radiometry, and Data Processing for Remote Sensing*, 136-143, Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, 1988.

Principal Investigator—Gary Rottman

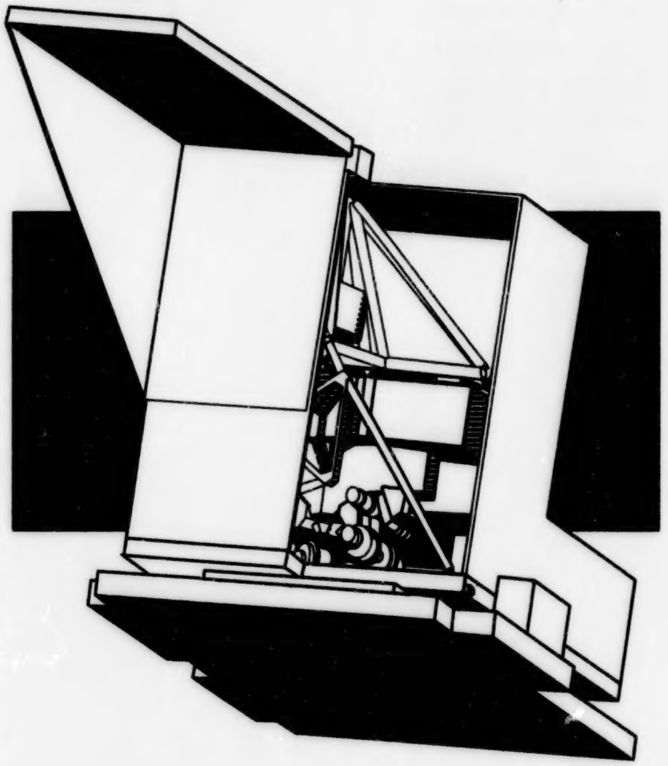
Gary Rottman, who holds an M.S. and Ph.D. in Physics from The Johns Hopkins University, has spent most of his professional career at the University of Colorado; however, he presently serves as Senior Scientist at the High-Altitude Observatory of the National Center for Atmospheric Research. His space research includes roles as Principal or Co-Investigator on numerous solar and atmospheric investigations, including Solar-Mesosphere Explorer, the Upper Atmosphere Research Satellite (UARS) SOLSTICE Program, and solar extreme ultraviolet Spartan and rocket programs.

Co-Investigators

Elaine R. Hansen, University of Colorado
George M. Lawrence, University of Colorado
Julius London, University of Colorado
Raymond G. Roble, National Center for Atmospheric Research
Paul C. Simon, Belgian Institute of Space Aeronomy
Tom N. Woods, University of Colorado

TES

TROPOSPHERIC EMISSION SPECTROMETER



HIGH SPECTRAL RESOLUTION INFRARED IMAGING FOURIER TRANSFORM SPECTROMETER

HERITAGE: ATMOS, SCRIBE

GENERATES THREE-DIMENSIONAL PROFILES ON A GLOBAL SCALE OF VIRTUALLY ALL INFRARED ACTIVE SPECIES FROM EARTH'S SURFACE TO THE LOWER STRATOSPHERE

MAXIMUM SAMPLING TIME OF 8 SEC,
WITH A SIGNAL-TO-NOISE RATIO OF UP TO 600:1

LIMB MODE: HEIGHT RESOLUTION = 2.3 KM, HEIGHT COVERAGE = 0-32 KM

TES is a high-resolution infrared imaging Fourier transform spectrometer with spectral coverage of 2.3 to 15.4 μm at a spectral resolution of 0.025 cm^{-1}, thus offering line-width-limited discrimination of essentially all radiatively active molecular species in the Earth's lower atmosphere. TES has the capability to make both limb and nadir observations. In the limb mode, TES has a height resolution of 2.3 km, with coverage from 0 to 32 km. In the down-looking modes, TES has a spatial resolution of 50 x 5 km (global) or 5 x 0.5 km (local), with a swath of 50 x 180 km (global) or 5 x 18 km (local). TES is a pointable instrument and can access any target within 45° of the local vertical, or produce regional transects up to 1,700 km without any gaps in coverage.

TES employs both the natural thermal emission of the surface and atmosphere and reflected sunlight, thereby providing day-night coverage anywhere on the globe.

Observations from TES will further understanding of long-term variations in the quantity, distribution, and mixing of minor gases in the troposphere, including sources, sinks, troposphere-stratosphere exchange, and the resulting effects on climate and the biosphere. TES will provide global maps of tropospheric ozone and its photochemical precursors. These observations will serve as primary inputs to a database of the three-dimensional distribution (on global, regional, and local scales) of gases important to tropospheric chemistry, troposphere-biosphere interactions, and troposphere-stratosphere exchange. Other objectives include:

- Simultaneous measurements of NO_y, CO, O_3, and H_2O for use in the determination of the global distribution of OH, an oxidant of central importance in tropospheric chemistry
- Measurements of SO_2 and NO_y as precursors to the strong acids H_2SO_4 and HNO_3, which are the main contributors to acid deposition
- Measurements of gradients of many tropospheric species in order to understand troposphere-stratosphere exchange
- Determination of long-term trends in radiatively active minor constituents in the lower atmosphere to investigate effects on global radiative balance and atmospheric dynamics.

TES measurements will help determine local atmospheric temperature and humidity profiles, local surface temperatures, and local surface reflectance and emittance. TES observations will also be used to study volcanic emissions for hazard mitigation, indications of the chemical state of the magma, eruption prediction, and quantification of the role of volcanoes as sources of atmospheric aerosols.

The aforementioned database will calibrate models of the present and future state of the Earth's lower atmosphere. These models will investigate topics such as:

- Biogeochemical cycles between the lower atmosphere and biosphere (primarily carbon monoxide and methane)
- Global climate modification caused by an increase in radiatively active gases
- Distribution and lifetimes of chlorofluorocarbons (CFCs) and halons, which contribute substantially to the depletion of stratospheric ozone
- Changes in the oxidizing power of the troposphere and the distribution of tropospheric ozone caused by urban and regional pollution sources, particularly carbon monoxide, nitrogen oxides, methane, and other hydrocarbons
- Acid deposition precursors
- Sources and sinks of species important to the generation of tropospheric and stratospheric aerosols
- Natural sources of trace gases such as methane from organic decay, nitrogen oxides from lightning, and sulphur compounds from volcanoes. ☆

Key TES Facts:

- In-house JPL development

For Further Information:

Glavich, T.A. and R. Beer, Tropospheric Emission Spectrometer for the Earth Observing System, in *Infrared Technology XVII*, vol. 1540, 148-159, Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, 1991.

TES Parameters

Measurement Approach

Nadir and limb viewing (fully targettable)

Spectral region 2.3 to 15.4 µm, with four single-line arrays optimized for different spectral regions

Swath: n/a

Spatial resolution: 0.75 x 7.5 mrad (narrow angle), 7.5 x 75 mrad (wide angle)

Accommodation Issues

Mass: 340 kg

Duty cycle: < 2% annually

Power: 430 W (average), 460 W (peak)

Data rate: 3.24 Mbps (average), 19.5 Mbps (peak)

Thermal control by: Stirling cycle cooler, heater, central thermal bus, radiator

Thermal operating range: 0-30°C

FOV: +45° to -71° along-track, ±71° cross-track

Instrument IFOV: 24 x 7.5 mrad (narrow angle), 240 x 75 mrad (wide angle)

Pointing requirements (platform+instrument, 3σ):

Control:	108 arcsec
Knowledge:	108 arcsec
Stability:	36 arcsec/sec
Jitter:	TBD

Physical size: 140 x 130 x 100 cm (stowed);
220 x 130 x 100 cm (deployed)

Principal Investigator—Reinhard Beer

Dr. Beer received a B.Sc. and Ph.D. in Physics from the University of Manchester, United Kingdom. He has been associated with the Jet Propulsion Laboratory since 1963; his current position is that of Senior Research Scientist and Supervisor of the Tropospheric Science Group, Earth and Space Sciences Division, and Manager of the Atmospheric and Oceanographic Sciences Section. Dr. Beer was chairman of the NASA Infrared Experiments Working Group and now serves as Co-Investigator on the Atmospheric Laboratory for Applications and Science (ATLAS) Atmospheric Trace Molecules Observed by Spectroscopy (ATMOS) experiment. He has been awarded the NASA Exceptional Scientific Achievement Medal for the discovery of extraterrestrial deuterium, three NASA group achievement awards, and numerous certificates of recognition.

Co-Investigators

Shepard A. Clough, Atmospheric and Environmental Research
Daniel J. Jacob, Harvard University
Jennifer A. Logan, Harvard University
Jack S. Margolis, Jet Propulsion Laboratory
John V. Martonchik, Jet Propulsion Laboratory
David G. Murcray, University of Denver
Curtis P. Rinsland, Langley Research Center
Stanley P. Sander, Jet Propulsion Laboratory
Fredric W. Taylor, Oxford University
Steven C. Wofsy, Harvard University

EOS Interdisciplinary Science Investigations

Mark Abbott
Eric J. Barron
Getulio T. Batista/
Jeffrey E. Richey
Peter G. Brewer
Josef Cihlar
Robert Dickinson
Jeff Dozier
William Grose
James E. Hansen
Graham Paul Harris
Dennis L. Hartmann
Bryan L. Isacks
Yann H. Kerr/
Soroosh Sorooshian
William K.M. Lau
John LeMarshall
W. Timothy Liu
Berrien Moore III
Peter Mouginis-Mark
Masato Murakami
John A. Pyle
Richard B. Rood
Drew Rothrock
David S. Schimel
Mark R. Schoeberl
Piers Sellers
Réjean Simard
Meric Srokosz
Byron D. Tapley
Bruce A. Wielicki

[illegible] 100 INTENTIONALLY BLANK

PRECEDING PAGE BLANK NOT FILMED

Coupled Atmosphere-Ocean Processes and Primary Production in the Southern Ocean

Principal Investigator—Mark Abbott

Dr. Abbott's investigation focuses on the dynamics of the Southern Ocean—its circulation, biology, and interaction with the atmosphere. Since the Southern Ocean plays a critical role in the global heat engine as well as the global carbon cycle, understanding of its functioning must be improved. The Antarctic circumpolar current dominates circulation in the Southern Ocean by regulating the oceanic component of the poleward heat flux; furthermore, this region serves as a large sink of atmospheric carbon dioxide. Knowledge of the magnitude and variability of both processes needs strengthening.

The Southern Ocean is characterized by strong eddy activity. Present ocean models do not adequately resolve these eddies, which are a significant component of regional circulation; thus, biogeochemical processes (generally nonlinear) will be incorporated into ocean dynamics models. The computational power required to resolve ocean eddies and the inclusion of rapidly varying biological processes exceeds the capabilities of conventional machines. So considerable effort has been invested in the design and implementation of models on massively parallel computers.

Two main goals drive this Interdisciplinary Science Investigation: 1) Understanding the processes that regulate atmospheric and oceanic heat and momentum flux in the Southern Ocean, and how they vary in time and space; and 2) understanding the temporal and spatial patterns of primary production, how they are regulated by physical forcing, and how these patterns are coupled with fluxes of biogenic carbon. This study will use pre-EOS measurements from U.S., Japanese, and European satellites, as well as EOS-era ocean and atmosphere observations. Many of these data sets will be used in model development and in data assimilation models. In addition to models, this investigation will generate several data sets relevant to biogeochemical and physical climate studies.

Dr. Abbott has been involved in the fields of oceanography and ecology for 12 years. He received his undergraduate degree in Conservation of Natural Resources from the University of California–Berkeley, and a Ph.D. in Ecology from the University of California–Davis. He has been affiliated with Oregon State University since 1988, currently as Associate Professor in the College of Oceanography. Dr. Abbott has served on numerous EOS-related committees, including the EOS Science Steering Committee and the Moderate-Resolution Imaging Spectroradiometer (MODIS) Panel. His research interests include studies of coupled biological/physical processes in the upper ocean and phytoplankton photosynthesis. Dr. Abbott has been selected as a MODIS Team Member, and is a member of the International Geosphere-Biosphere Program (IGBP) Global Ocean Euphotic Zone Study Working Group. ☆

Co-Investigators

Andrew Bennett, Oregon State University
Dudley B. Chelton, Oregon State University
Steven Esbensen, Oregon State University
Gad Levy, Oregon State University
James Richman, Oregon State University
P. Ted Strub, Oregon State University
Andrew C. Thomas, Atlantic Center for Remote Sensing of the Ocean
Leonard J. Walstad, Oregon State University

102 INTENTIONALLY BLANK
PRECEDING PAGE BLANK NOT FILMED

Global Water Cycle: Extension Across the Earth Sciences

Principal Investigator—Eric J. Barron

This Interdisciplinary Science Investigation focuses on the global water cycle to determine the scope of its interactions with all components of the Earth system, and to understand how it stimulates and regulates change on both global and regional scales. Dr. Barron plans to convert patterns observed from space into knowledge of the linked processes that determine the evolution of water in the Earth system. His research strategy involves generating a hierarchy of simulation models—from general circulation to mesoscale and basin-scale hydrologic models—assimilating EOS observations to produce information on physical and biological variables and process rates. The models will be verified through field studies to ensure proper calibration. Over the definition phase, these models will provide a methodology for resolving the presently unknown sources, sinks, and flux rates of the global water cycle. The consequent data will be used to document significant aspects of the water cycle and to enhance understanding of past variations. Such knowledge will help develop a predictive capability.

Dr. Barron received M.S. and Ph.D. degrees in Oceanography and Climatology from the University of Miami, and was a postdoctoral fellow at the National Center for Atmospheric Research (NCAR). Dr. Barron joined Pennsylvania State University as Director of the Earth System Science Center in 1986, and presently serves as a Professor of Geosciences as well. His research interests focus generally on global change and more specifically on numerical modeling of the climate system and the study of change throughout history. He is a member of numerous working groups related to these interests; in addition, he serves as Editor of *Global and Planetary Change.* ✩

Co-Investigators

Thomas Ackerman, Pennsylvania State University
Bruce Albrecht, Pennsylvania State University
Toby Carlson, Pennsylvania State University
John R. Christy, University of Alabama
Robert G. Crane, Pennsylvania State University
Kevin Furlong, Pennsylvania State University
Thomas Gardner, Pennsylvania State University
Steven J. Goodman, Marshall Space Flight Center
Lee R. Kump, Pennsylvania State University
Arthur Miller, Pennsylvania State University
Timothy L. Miller, Marshall Space Flight Center
Gary Petersen, Pennsylvania State University
Donna Peuquet, Pennsylvania State University
Franklin R. Robertson, Marshall Space Flight Center
Rudy Slingerland, Pennsylvania State University
Thomas Warner, Pennsylvania State University
Peter Webster, Pennsylvania State University
Brent Yarnal, Pennsylvania State University

Long-Term Monitoring of the Amazon Ecosystems through EOS: From Patterns to Processes

Principal Investigator—Getulio T. Batista • Lead U.S. Co-Investigator—Jeffrey E. Richey

Amazonia proves unique among terrestrial ecosystems because of its spatial extent, the intimate interaction with the largest river on the planet, and the rate of change caused by human activity. Changes in the Amazon will certainly modify regional hydrology and chemistry, with significant potential to influence global climate patterns. Understanding the process dynamics of the Amazon system under natural conditions is of high scientific priority and is an essential prerequisite for modeling global change. The goal of this investigation is to describe the routing of water and its chemical load from precipitation through the drainage system, to the mainstream and ocean, and back to the atmosphere under conditions of changing land use. Dr. Batista's group will model the land phase of the hydrologic cycle in undisturbed and deforested experimental basins, and will examine eutrophication processes in the newly created reservoirs. Dr. Richey's group will perform regional-scale hydrologic modeling by coupling forest structure, biogeochemical cycling, and sediment transport measurements. Data for these studies will come from EOS sensors, climatological networks, and the field observations.

With a Ph.D. in Agronomy and Remote Sensing conferred by Purdue University in 1981, Dr. Batista has focused his research in the areas of crop identification and conditions assessment, yield prediction modeling, scene characteristics and classification accuracy, and crop field radiometry. Since 1971, he has been affiliated with the Instituto Nacional de Pesquisas Espaciais. He was the Head of the Remote Sensing Department from 1982 to 1987, and Deputy Director of their Remote Sensing Directorate from 1985 to 1987.

Dr. Richey is a Professor of Oceanography at the University of Washington. He holds a B.A. in Biology from Stanford University, an M.S. in Environmental Engineering from the University of North Carolina, and a Ph.D in Ecology from the University of California–Davis. Dr. Richey is best known for work in ecosystem analysis and aquatic biogeochemistry. Since 1982, he has been Principal Investigator of the joint U.S./Brazil CAMREX project on the hydrology, biogeochemistry, and sediment transport of the Amazon River system. ☆

Co-Investigators

John B. Adams, University of Washington
Diogenes S. Alves, Instituto Nacional de Pesquisas Espaciais
Marcio N. Barbosa, Instituto Nacional de Pesquisas Espaciais
Thomas Dunne, University of Washington
Bruce R. Forsberg, Instituto Nacional de Pesquisas da Amazonia
Hermann Kux, Instituto Nacional de Pesquisas Espaciais
John M. Melack, University of California–Santa Barbara
Carlos Nobre, Instituto Nacional de Pesquisas Espaciais
Evlyn M.L.M. Novo, Instituto Nacional de Pesquisas Espaciais
Yosio E. Shimabukuro, Instituto Nacional de Pesquisas Espaciais
Joao V. Soares, Instituto Nacional de Pesquisas Espaciais
Compton J. Tucker, Goddard Space Flight Center
José C. Tundisi, Universidade de São Paulo
Dalton Valeriano, Instituto Nacional de Pesquisas Espaciais
Reynaldo L. Victoria, Universidade de São Paulo
John M. Wallace, University of Washington

Biogeochemical Fluxes at the Ocean/Atmosphere Interface

Principal Investigator—Peter G. Brewer

Dr. Brewer's investigation focuses on the fate of solar radiation incident on the oceans with its pronounced chemical, physical, and biological consequences, and the feedback of the gaseous products of these interactions through the agency of wind, waves, and circulation to the marine atmosphere. Topics to be covered include oceanic photochemistry, pigments, ocean biological processes, surface slicks and chemical modification of surfaces, surface waves and momentum transfer, and biogenic gas fluxes and their linkage through models. The overarching theme is to derive Earth-scale constraints in these important processes through the combination of local data sets with satellite imagery. A further benefit will be the construction of global-scale views of critical processes from the complex interplay of field data and satellite observables. Cooperation with major field programs such as the Joint Global Ocean Flux Study (JGOFS) and World Ocean Circulation Experiment (WOCE) will take place.

Dr. Brewer received his undergraduate and Ph.D. degrees from Liverpool University, and has over 20 years of experience in oceanography and marine chemistry. From 1967 to 1991, he was affiliated with the Woods Hole Oceanographic Institution (WHOI). In 1991, he was named President and Chief Executive Officer of the Monterey Bay Aquarium Research Institute. He is author or co-author of more than 70 scientific papers. From 1981 to 1983, he also was Program Director of Marine Chemistry at the National Science Foundation; in addition to teaching duties at WHOI, he chaired or served on numerous committees involved in marine research and global studies, as well as serving as editor or associate editor of related journals. Dr. Brewer's current research focuses on the global carbon cycle. He has served as Chairman of the U.S. Global Ocean Flux Study, and was past Vice Chairman of the International JGOFS. He is a Fellow of the American Geophysical Union and a Fellow of the American Association for the Advancement of Science. ✩

Co-Investigators

Neil V. Blough, Woods Hole Oceanographic Institution
Dennis Clark, National Environmental Satellite, Data, and Information Service
John W.H. Dacey, Woods Hole Oceanographic Institution
Wayne Esaias, Goddard Space Flight Center
Nelson M. Frew, Woods Hole Oceanographic Institution
David M. Glover, Woods Hole Oceanographic Institution
Catherine Goyet, Woods Hole Oceanographic Institution
Robert J. Olson, Woods Hole Oceanographic Institution
Edward T. Peltzer, Woods Hole Oceanographic Institution
Daniel J. Repeta, Woods Hole Oceanographic Institution
Anne M. Thompson, Goddard Space Flight Center
James A. Yoder, University of Rhode Island
Oliver C. Zafiriou, Woods Hole Oceanographic Institution

Northern Biosphere Observation and Modeling Experiment

Principal Investigator—Josef Cihlar

This Interdisciplinary Science Investigation builds on work accomplished or planned in Canada. Team members will research, develop, and demonstrate a Northern Biosphere Information System (NBIS) to routinely monitor terrestrial vegetation from space, with an emphasis on the role of terrestrial vegetation at mid- and high-latitudes. Initial model and algorithm development—complete with representative data products (e.g., a vegetation map of Canada)—will be accomplished prior to launch of the EOS satellites. EOS data will be optimized and applied over the Canadian land mass using NBIS, and vegetation growth models will be developed to produce digital maps of net change in carbon storage for two different years after EOS launch. One or more succession models and digital maps of future vegetation distribution over Canada will also be developed based on observed or postulated changes in environmental conditions.

Dr. Cihlar holds degrees in Soil Science, Physical Geography, and Remote Sensing (Ph.D. from the University of Kansas, 1975), and has concentrated his research interests on renewable resources and data acquisition/analysis for land applications. He joined the Canada Centre for Remote Sensing (CCRS) as an Environmental Scientist in 1975. Since 1979, he has been responsible for applications development at CCRS. Dr. Cihlar is presently involved in planning the use of space observations for global change studies. He leads the Remote-Sensing Technical Group, which reports to the Royal Society of Canada, and is a member of the International Geosphere-Biosphere Program (IGBP) Working Group on Data and Information Systems. ☆

Co-Investigators

Francis J. Ahern, Canada Centre for Remote Sensing
Michael Apps, Canadian Forestry Service
Jean Beaubien, Canadian Forestry Service
Terry Carleton, University of Toronto
Raymond Desjardin, Central Experimental Farm
Terry Fisher, Canada Centre for Remote Sensing
Bert Guindon, Canada Centre for Remote Sensing
Crawford Holling, University of Florida
Ken Lertzman, Simon Fraser University
Joe Lowe, Canadian Forestry Service
Philippe Teillet, Canada Centre for Remote Sensing

NCAR Project to Interface Modeling on Global and Regional Scales with EOS Observations

Principal Investigator—Robert Dickinson

Dr. Dickinson's investigation involves modeling, data analysis, data systems, and archiving—all directed toward improving global and mesoscale climate models at the National Center for Atmospheric Research (NCAR). As with other Interdisciplinary Investigations, the ultimate goal is to develop more reliable models and to promote higher confidence in global change predictions. Sensitivity studies of how EOS data can be applied to model improvement will be carried out for several focused areas, including the land surface in both global and regional applications, the sea ice component, the role of clouds, and atmospheric profiles of latent heat release. Recently developed techniques that allow assimilation of hydrological and surface fields will use EOS observations to obtain global data sets, which will validate and provide boundary conditions to the models. EOS observations also will be used to improve parameterizations of key processes within the models. In addition, the investigation will engage in long-term monitoring of atmospheric properties from operational satellite data, links between EOS sensor systems and model-generated fields, data visualization and archiving in the context of model requirements, maintenance of an EOS data archive, and exploration of new methodologies for organizing and archiving global data sets.

Dr. Dickinson has a long-standing relationship with NCAR, dating back to his initial employ in 1968 and eventual advancement to the position of Deputy Director, Climate and Global Dynamics Division. He is currently at the University of Arizona. He is a member of the U.S. National Academy of Sciences and is active in efforts of the National Research Council, the American Geophysical Union, the International Geosphere-Biosphere Program, the World Climate Research Program, and the American Meteorological Society. He has over 150 refereed publications to his credit. He is a Fellow of the American Association for the Advancement of Science, the American Geophysical Union, and the American Meteorological Society (AMS), and was awarded the AMS Jule G. Charney Award in 1988. ☆

Co-Investigators

Richard E. Carbone, National Center for Atmospheric Research
James A. Coakley, Oregon State University
William Emery, University of Colorado
Ronald M. Errico, National Center for Atmospheric Research
John C. Gille, National Center for Atmospheric Research
Filippo Giorgi, National Center for Atmospheric Research
Dean Graetz, Commonwealth Scientific and Industrial Research Organization
Robert D. Haskins, Jet Propulsion Laboratory
Ann Henderson-Sellers, Macquarie University
Roy L. Jenne, National Center for Atmospheric Research
Akira Kasahara, National Center for Atmospheric Research
Jeffrey T. Kiehl, National Center for Atmospheric Research
William A. Reiners, University of Wyoming
Kevin E. Trenberth, National Center for Atmospheric Research
Warren M. Washington, National Center for Atmospheric Research
Richard W. Zurek, Jet Propulsion Laboratory

Hydrology, Hydrochemical Modeling, and Remote Sensing in Seasonally Snow-Covered Alpine Drainage Basins

Principal Investigator—Jeff Dozier

Examination of the hydrologic component of global climate change requires a global understanding of the hydrology and hydrochemistry of alpine areas. Seasonally snow-covered areas of the Earth's mountain ranges prove important components of the global hydrologic cycle, even though they cover only a small portion of the Earth's surface area. For example, snow melt in the Sierra Nevada serves as the major water supply for the agricultural community of California's central valley. Furthermore, many alpine basins will be sensitive to changes in the amount and chemistry of precipitation—a result of their small groundwater reservoirs, the predominance of intrusive igneous rocks that weather slowly, the thin acidic soils, the large amount of precipitation, and their low buffering ability.

Knowledge of the hydrologic cycle in these topographically rugged basins is limited by poor understanding of the processes that determine the hydrologic cycle and the inability to collect data in sufficient quantities to characterize and model these processes. For instance, the simple measurement of snow pack total water volume is made difficult by the large variations associated with rugged terrain. We have established that snow accumulation and distribution in alpine basins can be classified into similar zones of snow water equivalence based on radiation, slope, and elevation. Another recent development involved the application of synthetic aperture radar (SAR) technology to directly measure snow properties in the Oetztal Alps of western Austria. One of the next challenges involves combining this information into a distributed snow-melt model that predicts the timing and magnitude of snow-melt runoff from energy balance parameters. Such a model will prove a useful management tool for hydrologists concerned with maximizing water yield and minimizing the impacts of floods.

Recent advances in the study of the alpine hydrologic cycle—derived from both models and field measurements—indicate that snow packs in alpine basins store wet and dry deposited chemical species throughout the snow accumulation season. Solutes are released in meltwater from the snow pack differentially, with the first meltwater having a chemical concentration four to ten times higher than the mean. Typically, the first 20 percent of meltwater contains about 80 percent of the solutes stored in the seasonal snow pack. Numerous studies have shown that this "ionic pulse" can cause a rapid change in the chemical composition of lakes and streams, with lethal effects on the local biota in some cases. Snow physics studies have shown that the magnitude of the ionic pulse is a function of both the number of melt-freeze cycles the snow pack undergoes and the rate of melt. By modeling energy inputs into the snow pack and sampling the chemical content at the time of maximum accumulation, it may be possible to predict the magnitude and length of the ionic pulse over large areas. Tracer studies of air flow over mountainous regions can identify source regions of precipitation chemistry.

This Interdisciplinary Investigation will use data from several EOS-era instruments (i.e., MODIS, ASTER, CERES, MISR, and MIMR) to monitor hydrologic conditions in watersheds and to drive hydrologic models. In the intervening years, data will be obtained from the NASA aircraft program (AVIRIS and AIRSAR) and from Landsat and SPOT. Hydrological and chemical sampling will be done in the field, and data will also be acquired from other programs that are investigating effects of atmospheric pollutants on high-elevation watersheds.

Dr. Dozier received a B.A. in Geography from California State University–Hayward in 1968, and a M.Sc. in 1969 and Ph.D. in 1973 from the University of Michigan. He has taught at the University of California–Santa Barbara since 1974, where he is now a Professor of Geography. He has over 100 publications to his credit, covering a diverse range of research interests: Snow hydrology, Earth system science, radiative transfer in snow, remote sensing and data systems, image processing, and terrain analysis. He is a Fellow of the American Geophysical Union, Editor of *Geophysical Research Letters*, and a Distinguished Visiting Scientist at the Jet Propulsion Laboratory. Dr. Dozier is a Principal Investigator on several NASA projects; with Dr. Michael Stonebraker of the University of California–Berkeley, he is co-Principal Investigator on Digital Equipment Corporation's flagship external research project, "Sequoia 2000: Large Capacity Object Servers to Support Global Change Research." From 1990-1992, he served as the EOS Project Scientist. ☆

Co-Investigators

Roger C. Bales, University of Arizona
John M. Melack, University of California–Santa Barbara
Kathy A. Tonnessen, National Park Service
Mark W. Williams, University of Colorado

Observational and Modeling Studies of Radiative, Chemical, and Dynamical Interactions in the Earth's Atmosphere

Principal Investigator—William Grose

Dr. Grose and his co-investigators will examine the radiative, chemical, and dynamical processes that determine the circulation, thermal structure, and distribution of the Earth's atmospheric constituents; the interactive coupling among these processes will receive emphasis. The investigation will involve observational analysis and diagnostic interpretation of meteorological and constituent data from EOS instruments, in conjunction with other satellite, balloon, ground-based, and aircraft data. Complementary atmospheric simulation studies will result in a hierarchy of models that incorporate radiative, chemical, and dynamical processes to varying degrees of complexity for the troposphere, stratosphere, and mesosphere. The modeling and data analysis studies will serve a dual purpose: 1) Increase understanding of fundamental processes and 2) aid in development of a predictive capability for global change studies.

William Grose received an M.S. in Physics from the College of William and Mary and a Ph.D. in Aerospace Engineering from Virginia Polytechnic Institute and State University. He is a Senior Research Scientist and Assistant Head of the Theoretical Studies Branch, Atmospheric Sciences Division at Langley Research Center, where he has helped develop several three-dimensional models for studying atmospheric dynamics and trace constituent transport. In addition to his role as Principal Investigator for this Interdisciplinary Investigation, he is a Principal Investigator and member of the Upper Atmosphere Research Satellite (UARS) Science Team. Dr. Grose has been a Visiting Scientist with the United Kingdom Universities' Atmospheric Modeling Group at the University of Reading, and was recipient of the NASA Medal for Exceptional Scientific Achievement in 1986. ☆

Co-Investigators

Thomas Blackshear, Langley Research Center
Richard S. Eckman, Langley Research Center
Duncan Fairlie, Langley Research Center
Rolando Garcia, National Center for Atmospheric Research
Alan O'Neill, British Meteorological Office
R. Bradley Pierce, Langley Research Center
Ellis E. Remsberg, Langley Research Center
Murry L. Salby, University of Colorado
Susan Solomon, U.S. Department of Commerce
Richard E. Turner, Langley Research Center

Interannual Variability of the Global Carbon, Energy, and Hydrologic Cycles

Principal Investigator—James E. Hansen

Dr. Hansen and his co-investigators will investigate the interannual variability of key global parameters and processes in the global carbon, thermal energy, and hydrologic cycles. Team members will develop, analyze, and make available global geophysical data sets derived from pre-EOS and EOS observations. Analysis will involve studies of several specific interdisciplinary problems, each focused on interactions among components of the Earth system. Expected near-term products include knowledge of certain Earth system processes that can be investigated via large-scale interannual variability of a number of observed parameters; a mini EOS-type collection of data sets available in convenient form to other investigators; and improved definition of global measurement and data set needs for EOS.

The pre-EOS study of the energy, carbon, and hydrologic cycles will focus on global change during the past decade, including the natural global experiment provided by the eruption of Mt. Pinatubo in June 1991. This infusion of stratospheric aerosols will be examined along with other competing mechanisms, such as the 1992 El Niño and ozone depletion, to determine cumulative effects. The study will involve analysis of satellite and other data on forcings and feedbacks, the use of these data in global models, and comparison of model results with global diagnostic data.

Dr. Hansen heads the Goddard Institute for Space Studies (GISS). A student of Astronomy and Physics (Ph.D. from the University of Iowa, 1967), he has focused his research primarily on radiative transfer in planetary atmospheres and related interpretation of remote soundings, development of simplified climate models and three-dimensional global models, and the study of climate mechanisms. In addition to his research and administrative duties at GISS, he serves as Adjunct Professor at Columbia University. ☆

Co-Investigators

James K.B. Bishop, Columbia University
Barbara Carlson, Goddard Institute for Space Studies
Anthony del Genio, Goddard Institute for Space Studies
Inez Fung, Goddard Institute for Space Studies
Andrew Lacis, Goddard Institute for Space Studies
Michael J. Prather, University of California–Irvine
David H. Rind, Goddard Institute for Space Studies
William B. Rossow, Goddard Institute for Space Studies
Peter H. Stone, Massachusetts Institute of Technology

Interdisciplinary Studies of the Relationships between Climate, Ocean Circulation, Biological Processes, and Renewable Marine Resources

Principal Investigator—Graham Paul Harris

This Interdisciplinary Science Investigation addresses activities extending from basic to applied research, all of which are concerned with interannual variability in climate, biological processes, ocean-atmosphere interactions, and marine fisheries resources. Dr. Harris and his co-investigators will study the links between these processes in Australasian waters and fisheries. Interactions between climatic El Niño Southern Oscillation (ENSO) events and ocean processes will receive emphasis, as will oceanic productivity in tropical waters and the subtropical convergence region south of Australia and New Zealand. These process studies will use existing satellite data, data from new sensors, and EOS satellite observations. The Sea-Viewing Wide Field Sensor (SeaWiFS) mission will provide ocean color data in the years before launch of the Moderate-Resolution Imaging Spectroradiometer (MODIS). Suitable algorithms will be developed at all stages to measure phytoplankton biomass and productivity from space. At longer time scales, there is an important feedback between ocean productivity and global change, because the subtropical convergence region of the southern hemisphere is one of the most important sites of "new" production in the world's oceans. Construction of a high-bit-rate (X-band) receiving station in Hobart will help strengthen the science goals of this investigation.

With academic preparation in Biology and Ecology (Ph.D. from Imperial College–London, 1969), Dr. Harris has dedicated his career to the interaction of physical and biological processes, and their effect on aquatic resources. His work focused on the Great Lakes (Canada) from 1969 to 1983; his remote-sensing career began with the ERTS-1 simulation missions. Since 1984, he has been affiliated with Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) Divisions of Fisheries Research and Oceanography, first as Program Leader then Head of the Fisheries Remote-Sensing Group. Dr. Harris is Chair or member of numerous advisory committees and working groups on ocean remote sensing, including the Australian Joint Global Ocean Flux Study (JGOFS) Committee; and is member of editorial boards of publications on marine ecology and oceanography. He is now Director of the CSIRO Office of Space Science and Applications, and a member of the International JGOFS Executive Committee. ☆

Co-Investigators

John Church, Commonwealth Scientific and Industrial Research Organization
Richard Coleman, University of Sydney
Peter Craig, Commonwealth Scientific and Industrial Research Organization
George Cresswell, Commonwealth Scientific and Industrial Research Organization
Chris Fandrey, Commonwealth Scientific and Industrial Research Organization
J.S. Godfrey, Commonwealth Scientific and Industrial Research Organization
V. Lyne, Commonwealth Scientific and Industrial Research Organization
Denis Mackey, Commonwealth Scientific and Industrial Research Organization
Trevor McDougall, Commonwealth Scientific and Industrial Research Organization
Gary Meyers, Commonwealth Scientific and Industrial Research Organization
Carl Nilsson, Commonwealth Scientific and Industrial Research Organization
M. Nunez, University of Tasmania
John Parslow, Commonwealth Scientific and Industrial Research Organization
Graeme I. Pearman, Commonwealth Scientific and Industrial Research Organization

Climate Processes Over the Oceans

Principal Investigator—Dennis L. Hartmann

Dr. Hartmann's investigation will use data from various satellite instruments, data from other sources, and models to construct an integrated view of atmospheric climate over the oceans. Primary problem areas to be addressed include the role of clouds, radiation, water vapor, and precipitation in climate change, and the role of ocean-atmosphere interactions in the energy and hydrologic cycles. The physical processes considered involve boundary layer dynamics and resulting fluxes, cloud-scale and mesoscale dynamics, and cloud physics. Incorporation of the interactions between clouds and radiative fluxes and between scales of motion (i.e., from boundary layer turbulence to the largest scales of planetary motion) all prove necessary to achieve a comprehensive understanding of climate, enhancing researchers' ability to predict future change. Simultaneous measurements of a variety of physical variables derived from EOS observations will be used to better understand the atmospheric component of the climate system and its interactions with the ocean.

Dennis Hartmann received his Ph.D. in Geophysical Fluid Dynamics from Princeton University in 1975. He has been on the faculty of Atmospheric Sciences at the University of Washington since 1977, and an adjunct faculty member of the Quaternary Research Center since 1978. His main research interests are in the areas of global climate, large-scale dynamics, and the radiative energy balance of the Earth; he has published over 50 research papers on these topics. Dr. Hartmann served as Principal Investigator in the Earth Radiation Budget Experiment (ERBE) and the Airborne Antarctic Ozone Experiment (AAOE), for which he received NASA Group Achievement awards. ☆

Co-Investigators

Robert A. Brown, University of Washington
Robert A. Houze, University of Washington
Kristina B. Katsaros, IFREMER–Centre de Brest, France, and University of Washington
Conway B. Leovy, University of Washington

Climate, Erosion, and Tectonics in the Andes and Other Mountain Systems

Principal Investigator—Bryan L. Isacks

This Interdisciplinary Science Investigation will further understanding of the interactions between the atmosphere and the lithosphere in terrestrial mountain systems where those interactions are most dynamic and complex. Climatic and tectonic processes in mountain belts combine to produce the Earth's highest rates of weathering, erosion, and transport of crustal materials by ice, water, and wind. The Andes mountain belt, straddling a hemispheric variation in climate, serves as a natural "laboratory" for investigation of this important part of the terrestrial land surface system. The study includes two closely related components: 1) A comprehensive description of the modern mountain land surface system, and 2) determination of the changes in climate from the last glacial to the modern interglacial period.

The first component will produce a high-resolution view of the temporal and spatial variability of modern Andean climate and the associated hydrological/erosional regime, including detection of human-induced change. Time scales of targeted processes range from decades down do the brief intervals characteristic of the large meteorological, hydrological, geomorphological, and tectonic "events" that dominate atmospheric interactions with the lithosphere. Examples of rapidly acting processes include the following:

- Catastrophic erosional, mass transport, and depositional fluxes associated with large storm systems, floods, earthquakes, or volcanic eruptions
- Injection of large amounts of material into the atmosphere by dust storms in the arid regions of the central Andes
- Changes in coastal regions as a result of earthquake movements and resulting responses of rivers and coastal processes.

Seasonal, interannual, and decadal changes in the geomorphological, hydrological, and vegetational features will also be determined and correlated with climatic parameters derived from available four-dimensional data assimilation models. Detection of longer term, pre-EOS change will be determined by analysis of all available sources covering the latter part of this century.

The second component of this study will focus on the critical transition period from the Last Glacial Maximum 18,000 years ago to the present. Features recording the climate system during this period include glacial and perigacial land forms, lake paleo-shorelines, wind direction indicators, and fluvially produced topography not in equilibrium with modern runoff. Systematic mapping and analysis of these features in comparison to the modern regime complements ground-based studies of climate change to establish regional patterns, thereby yielding a better understanding of the spatial complexity of terrestrial mountain system climates.

The basis for both components involves regional-scale mapping and/or monitoring of topography, geology, climate, hydrology, land cover, and tectonic deformation, all integrated into a computerized geographic information system designed to deal with change through time. An important output of this work will be the identification and monitoring of sensitive indicators of contemporary climate change such as glacier extent, lake levels, and elevation-dependent vegetation boundaries.

Dr. Isacks received a Ph.D. in Seismology and Tectonics from Columbia University in 1965, joined the Cornell faculty in 1971, and is currently the William and Katherine Snee Professor of Geological Sciences and the Director of the Institute for the Study of the Continents. In 1981, Dr. Isacks initiated the Cornell Andes Project. ☆

Co-Investigators

Richard Allmendinger, Cornell University
Arthur L. Bloom, Cornell University
Eric J. Fielding, Cornell University
Teresa Jordan, Cornell University
Suzanne M. Kay, Cornell University
William Philpot, Cornell University

The Hydrologic Cycle and Climatic Processes in Arid and Semi-Arid Lands

Principal Investigator—Yann H. Kerr • Lead U.S. Co-Investigator—Soroosh Sorooshian

Through the use of remotely sensed data, researchers are now able to monitor the responses to changes in hydrologic fluxes. With an effective linkage between remote-sensing data and hydrologic models, a better understanding of the processes that control the changes in hydrologic storages and fluxes can be generated. Such knowledge will allow scientists to better assess the role of the hydrologic cycle in a global context and to predict the effects of climatic or human-induced change.

Using several sites in the Sahel, Dr. Kerr's research seeks to quantify and monitor natural and anthropogenically induced changes in hydrologically relevant land surface parameters. This regional-scale emphasis also will yield an improved understanding of the Earth/atmosphere response to changes in land surface characteristics. A global data set will be defined and algorithms/models developed to generate geophysical parameters, which will then be used to monitor seasonal and year-to-year changes. These parameters include surface temperature, roughness, moisture, vegetation characteristics, evapotranspiration, rainfall, shortwave incoming flux, and albedo. Soil-vegetation interactions and hydrologic feedback mechanisms will also be studied.

Dr. Sorooshian's research focuses initially on understanding hydrologic processes at the sub-watershed and watershed scale, then expanding to basin and regional scales. Data will be used to derive distributed basin characteristics, as well as inputs to water/energy balance simulation models. These results will help to identify the dominant processes that control hydrologic fluxes at various spatial and temporal scales, and to develop improved hydrologic modeling and prediction capabilities during both storm and inter-storm periods. Initially, observations will be collected at the Arizona-Sonoran desert of North America; the study will later be extended to the African sites that are the focus of the Laboratoire d'Etudes et de Recherches en Télédétection Spatiale (LERTS) group.

Dr. Kerr received a Ph.D. from the Université P. Sabatier–Toulouse, France. From 1980 to 1985, he was with the Centre National d'Etudes Spatiales in Toulouse; in 1985, he joined LERTS as a research scientist. He took a leave of absence to work at the Jet Propulsion Laboratory from 1987 to 1988. Dr. Kerr has worked mainly with Meteosat, Nimbus-7 Scanning Multispectral Microwave Radiometer (SMMR), and Advanced Very High-Resolution Radiometer (AVHRR) data concerning the use of thermal infrared and passive microwaves for the determination of hydrologic cycle parameters. He has been involved with several field experiments in Africa, as well as the 1987 EOS Simultaneity Experiment, and is a Principal Investigator for ERS-1 and MOS-1 EMDUP.

Dr. Sorooshian is Professor of Hydrology and Water Resources (and department head), and of Systems and Industrial Engineering at the University of Arizona–Tucson. He holds an M.S. and Ph.D. in Systems Engineering and Water Resources Systems, respectively, from the University of California–Los Angeles. Dr. Sorooshian is best known for his work on hydrologic modeling, specifically rainfall runoff models, and the development of parameter estimation and calibration techniques. He has served as Principal Investigator on numerous projects related to hydrologic modeling, and is currently the Editor of *Water Resources Research*, published by the American Geophysical Union. ☆

Co-Investigators

Gerard Dedieu, Laboratoire d'Etudes et de Recherches en Télédétection Spatiale
David C. Goodrich, USDA/Agricultural Research Service
Michael D. Hudlow, NOAA/National Weather Service
Alfredo R. Huete, University of Arizona
Jacques Imbernon, Institut de Recherche en Agronomie Tropicale
Ray D. Jackson, USDA/Agricultural Research Service
J.P. Lagouarde, Institut National de Recherche Agronomique
M. Susan Moran, USDA/Agricultural Research Service
Bernard Seguin, Institut National de Recherche Agronomique
Philip N. Slater, University of Arizona
James Smith, Princeton University
Mike Sully, University of Arizona
Alain Vidal, CEMAGREF-ENGREF
David Woolhiser, USDA/Agricultural Research Service

Global Hydrologic Processes and Climate

Principal Investigator—William K.M. Lau

The global water and energy cycle is an integral component of the Earth's climate, providing the linkages between the atmosphere, land, and ocean. To better understand global climate, a thorough knowledge of the hydrologic cycle must be developed. This Interdisciplinary Science Investigation will describe the physical processes that contribute to the mean and fluctuations of the global hydrologic and energy cycle. To achieve this goal, the investigation will focus on three closely linked scientific objectives aimed at improving understanding of the following:

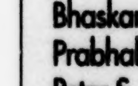
- The physical mechanisms of atmospheric hydrologic processes (in particular precipitation) and their interaction with the dynamics and radiative properties of the atmosphere
- The role of hydrologic processes in large-scale ocean/atmosphere/land interaction leading to natural fluctuation of the global climate system over a variety of time scales
- The role of land surface processes (including storage) in the global hydrologic cycle, with emphasis on the interaction and integration of regional and global scales.

This research project makes extensive use of data collected from both existing satellite missions and EOS. Results obtained from pre-EOS observations are currently being used to further understanding of global hydrologic processes through model development and data analysis, and to guide instrument design for the launch phase. A synergistic approach based on analysis of data from space and non-space platforms will be emphasized.

Dr. Lau received a Ph.D. in Atmospheric Sciences from the University of Washington in 1977. He was Assistant Professor at the Naval Postgraduate School until 1981. Since then, he has been a Senior Research Meteorologist in the Laboratory for Atmospheres at Goddard Space Flight Center. Currently, he is Head of the Climate and Radiation Branch of said Laboratory and is a Senior Goddard Fellow. His areas of research expertise include climate dynamics, tropical and monsoon meteorology, and ocean-atmosphere interaction. He has published over 50 research papers in the refereed literature. He is Chairman of the American Meteorological Society Committee on Climate Variations, member of the Tropical Ocean Global Atmosphere (TOGA)/Coupled Ocean-Atmosphere Response Experiment (COARE) Science Working Team, and a science team member of the Tropical Rainfall Measuring Mission (TRMM). ☆

Co-Investigators

Robert F. Adler, Goddard Space Flight Center
John R. Bates, Goddard Space Flight Center
Thomas L. Bell, Goddard Space Flight Center
Wilfried H. Brutsaert, Cornell University
Bhaskar Choudhury, Goddard Space Flight Center
Prabhakara Cuddapah, Goddard Space Flight Center
Peter S. Eagleson, Massachusetts Institute of Technology
Edwin T. Engman, Goddard Space Flight Center
Marvin A. Geller, State University of New York–Stony Brook
Robert J. Gurney, University of Reading
H. Mark Helfand, Goddard Space Flight Center
N.C. Lau, NOAA/Geophysical Fluid Dynamics Laboratory
W. Timothy Liu, Jet Propulsion Laboratory
Roger Lukas, University of Hawaii
John L. Monteith, International Crop Research Institute
Masato Murakami, Meteorological Research Institute
Abraham Oort, NOAA/Geophysical Fluid Dynamics Laboratory
Sigfreid Schubert, Goddard Space Flight Center
Joanne Simpson, Goddard Space Flight Center
David O'C. Starr, Goddard Space Flight Center
Yogesh C. Sud, Goddard Space Flight Center
James A. Weinman, Goddard Space Flight Center
Warren J. Wiscombe, Goddard Space Flight Center
Eric F. Wood, Princeton University
Man-Li C. Wu, Goddard Space Flight Center



The Processing, Evaluation, and Impact on Numerical Weather Prediction of AIRS, AMSU, MODIS, and LAWS Data in the Tropics and Southern Hemisphere

Principal Investigator—John F. LeMarshall

This investigation involves the development of processing algorithms and techniques to derive geophysical parameters of significance to atmospheric science from the Atmospheric Infrared Sounder (AIRS), Advanced Microwave Sounding Unit (AMSU), and Moderate-Resolution Imaging Spectroradiometer (MODIS) instruments. Developing a methodology to assimilate these parameters into numerical weather prediction (NWP) models will receive emphasis, and an assessment of the utility of these data for this purpose will be verified. In tandem, intercomparison studies will be performed with the satellite data. As a first step, researchers will derive sounding data from the AMSU-A radiances available in 1994; these data will be evaluated to determine the benefits provided to ongoing studies of the Southern Hemisphere. Concurrently, research will be directed at producing a local capacity for the simulation, processing, and utilization of data from AIRS and MODIS, and for assimilation of the EOS processed data into NWP models.

Dr. Le Marshall received a Ph.D. in Physics from Monash University in 1972. His specialties include remote sensing and data assimilation. Current activities include land, oceanic, and atmospheric application of Advanced Very High-Resolution Radiometer (AVHRR) data, TIROS Operational Vertical Sounder (TOVS) data, and geostationary meteorological satellite data. He presently serves as Head of the Satellite and Remote-Sensing Group at the Bureau of Meteorology Research Centre in Melbourne, Australia, and is responsible for development and research related to satellite meteorology. ☆

Co-Investigators

William P. Bourke, Bureau of Meteorology Research Centre
David Griersmith, Bureau of Meteorology Research Centre
Graeme A. Kelly, ECMWF
Lance Leslie, Bureau of Meteorology Research Centre
Graham Mills, Bureau of Meteorology Research Centre
Kamal K. Puri, Bureau of Meteorology Research Centre

The Role of Air-Sea Exchanges and Ocean Circulation in Climate Variability

Principal Investigator—W. Timothy Liu

Dr. Liu's investigation builds upon ongoing studies of climate change related to the hydrologic and energy balances of the coupled ocean-atmosphere system. Current participation and leadership in field experiments, monitoring programs, modeling efforts, and flight missions of the World Climate Research Program (WCRP) and NASA serve as the foundation upon which to focus understanding of ocean-atmosphere responses to fluxes in momentum, energy, and moisture. Methods to monitor such surface forcings from space are being developed and improved. Eddy-resolving general circulation models (including thermodynamics) will be developed to provide a four-dimensional description of the storage and transport of heat and greenhouse gases in the ocean. EOS data will be incorporated as they become available. The ultimate goal is to improve diagnosis and prognosis of global change, with a discernable difference between natural and anthropogenic effects a necessary consequence.

W. Timothy Liu holds an M.S. and Ph.D. from the University of Washington. He has been a Principal Investigator on studies concerning air-sea interaction and satellite remote sensing since he joined the Jet Propulsion Laboratory in 1979. He is currently the leader of the Air-Sea Interaction and Climate Team, and the NASA Scatterometer (NSCAT) Project Scientist. Dr. Liu has served on numerous science working groups and advisory committees for NASA, the Tropical Ocean Global Atmosphere (TOGA) program, and World Ocean Circulation Experiment (WOCE). Dr. Liu is a Principal Investigator on both the NSCAT and Ocean Topography Experiment (TOPEX) science investigation teams, and has participated in many multi-national field experiments. He received the NASA Medal for Exceptional Scientific Achievement in 1990. ✩

Co-Investigators

Lee-Lueng Fu, Jet Propulsion Laboratory
Catherine Gautier, University of California–Santa Barbara
William R. Holland, National Center for Atmospheric Research
Paola Malanotte-Rizzoli, Massachusetts Institute of Technology
Pearn P. Niiler, Scripps Institution of Oceanography
William C. Patzert, Jet Propulsion Laboratory
Victor Zlotnicki, Jet Propulsion Laboratory

Changes in Biogeochemical Cycles

Principal Investigator—Berrien Moore III

The long-term goal of this Interdisciplinary Science Investigation is to understand the primary biogeochemical cycles of planet Earth. The strategy is to study how element cycles function: 1) In quasi-steady state systems in the absence of human-induced perturbations, and 2) in the transient state induced by human activity. The team will develop global, geographically specific, mathematical models and databases that describe ecosystem distribution and condition, the biological processes that determine the exchange of CO_2 and trace gases with the atmosphere, and the fluxes of carbon and nutrients to aquatic ecosystems. This suite of models will rest within an interactive information system, which will integrate a geographic information system, a remote-sensing system, a database management system, a graphics package, and a modern interface shell.

Dr. Moore earned a Ph.D. in Mathematics from the University of Virginia in 1969. He is best known internationally for his computer modeling of the global carbon cycle. Professor Moore's specific research interests include the application of geographic information systems and remote sensing in modeling ecosystem dynamics globally, and the use of inverse calculations to develop ocean models for use in carbon cycle investigations. He is well-published in ecosystems literature and in studies of the role of the ocean in the carbon cycle. He is involved in numerous related studies for NASA, the National Science Foundation, the Environmental Protection Agency, and the Department of Energy. Professor Moore is Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire. ☆

Co-Investigators

John Aber, University of New Hampshire
William Emanuel, Oak Ridge National Laboratory
Robert C. Harriss, University of New Hampshire
Jerry M. Melillo, Marine Biological Laboratory
Bruce Peterson, Marine Biological Laboratory
Barrett N. Rock, University of New Hampshire
David Skole, University of New Hampshire
Charles Vorosmarty, University of New Hampshire

A Global Assessment of Active Volcanism, Volcanic Hazards, and Volcanic Inputs to the Atmosphere from EOS

Principal Investigator—Peter J. Mouginis-Mark

The impact of volcanoes on the Earth system was dramatically demonstrated in 1991 by the eruptions of Mt. Pinatubo (Philippines) and Mt. Unzen (Japan). Mt. Pinatubo has had a near-global effect via the introduction of 20 to 30 megatons of sulfur dioxide and aerosols into the atmosphere, and represents the second largest eruption this century—second only to Mt. Katmai (Alaska) in 1912. The materials injected into the stratosphere by Mt. Pinatubo circled the Earth in only 3 weeks, and covered ~42 percent of the Earth's surface after only 2 months. Atmospheric models predict a global cooling of 0.5°C a year after the eruption. In Japan, Mt. Unzen killed dozens of people and caused major disruptions to local populations and air traffic.

This Interdisciplinary Science Investigation's objectives are three-fold: 1) To understand the physical processes associated with volcanic eruptions; 2) to investigate the manner by which sulfur dioxide, water vapor, carbon dioxide, and other volcanic gases are injected into the troposphere and stratosphere; and 3) to place the diverse volcanic eruptions into the context of the regional tectonic setting of the volcano. The degassing history of a lava flow or eruption plume may have a major effect on the local or hemispheric climate, depending on the rate of eruption, the magma chemistry, and pre-eruption storage characteristics of the magma. Through the analysis of ongoing eruptions, data from EOS surface imagers and atmospheric instruments are expected to significantly improve the understanding of how volcanoes work, and the short-term effects that eruptions have on weather and climate.

This Interdisciplinary Investigation will draw heavily on many of the EOS sensors, combining high spatial resolution images of near-vent activity and daily regional low-resolution views of eruption plume dispersal. In order to observe eruptions while they are in process, this investigation will contribute significantly to the development of a near-real-time response capability for the different EOS instruments. Such a capability is expected to be of benefit to numerous other studies of transient phenomena. This rapid response will be achieved via the production and distribution of algorithms suitable for the searching of synoptic data sets. Higher order data sets that document the characteristics of specific eruptions, the dispersal of eruption plumes, and the geology of individual volcanoes will be the primary archival products. These products will be transferred to the EOS Data and Information System (EOSDIS) and also maintained locally for access by the volcanology community at large.

Academically trained in environmental sciences (Ph.D. from Lancaster University, England, 1977), Dr. Mouginis-Mark has concentrated his research experience on volcanic phenomena, planetary geology, and remote sensing. He has been associated with the University of Hawaii since 1982, and presently serves as both Associate Head of the Planetary Geosciences Division and as Professor in the Department of Geology and Geosciences. He has been actively involved in NASA planetary and Earth orbital missions, study groups, and working committees within his field of research. In addition, he has recently served as Associate Editor of *Geology* and as Editor of the Planetology Section of *EOS*. ☆

Co-Investigators

John B. Adams, University of Washington
Joy A. Crisp, Jet Propulsion Laboratory
Peter Francis, University of Hawaii
Jonathan Gradie, University of Hawaii
Kenneth Jones, Jet Propulsion Laboratory
Anne B. Kahle, Jet Propulsion Laboratory
Arlin Krueger, Goddard Space Flight Center
David Pieri, Jet Propulsion Laboratory
William I. Rose, Michigan Technological University
Steven Self, University of Hawaii
Louis S. Walter, Goddard Space Flight Center
Lionel Wilson, University of Hawaii
Robert S. Wolff, Apple Computers, Inc.
Charles A. Wood, University of North Dakota
Howard A. Zebker, Jet Propulsion Laboratory

Investigation of the Atmosphere-Ocean-Land System Related to Climatic Processes

Principal Investigator—Masato Murakami

Dr. Murakami's Interdisciplinary Science Investigation provides a mixture of observational studies and climate modeling related to the atmosphere-ocean-land interactions through heat and momentum exchanges. His investigation consists of three components. First, researchers will develop algorithms for the objective identification of cloud types and the quantitative measurement of precipitation. Data validation of newly developed remote-sensing techniques will also be carried out. Based on these products, observational studies will be conducted to examine the atmospheric system associated with various rainfall activities. The role of atmospheric minor constituents in climate changes will also be examined. Secondly, researchers will monitor climatic changes of the sea surface temperature, sea level, and sea surface wind through the use of satellite observations, eventually generating data sets that can be incorporated in the ocean modeling study of seasonal/interannual variations of the Pacific and the mid-latitudinal eddies of the ocean. Finally, researchers will examine land surface conditions, such as ground wetness and snow mass. An atmospheric general circulation model will be incorporated to evaluate the impact of anomalous surface conditions on climate change. Project components will exchange results and data with other components to ensure overall understanding of the Earth system.

Dr. Murakami was academically trained in Geophysics and Meteorology at the University of Tokyo, and earned his D.Sc. from that institution in 1974. Except for a 2-year position at Florida State University, Dr. Murakami has been affiliated with the Meteorological Research Institute for his entire professional career. Presently, he is Chief of Laboratory in the Typhoon Research Division. His research interests include tropical, monsoon, and satellitemeteorology. ✫

Co-Investigators

Tadao Aoki, Meteorological Research Institute
Masahiro Endoh, Meteorological Research Institute
Toshifumi Fujimoto, Meteorological Research Institute
Masashi Fukabori, Meteorological Research Institute
Toshiro Inoue, Meteorological Research Institute
Masafumi Kamachi, Meteorological Research Institute
Y. Kitamura, Meteorological Research Institute
Akio Kitoh, Meteorological Research Institute
Yukio Makino, Meteorological Research Institute
Tetsuo Nakazawa, Meteorological Research Institute
Toru Sasaki, Meteorological Research Institute
Akira Shibata, Meteorological Research Institute
Kenzo Shuto, Meteorological Research Institute
Masato Sugi, Meteorological Research Institute
Tatsushi Tokioka, Meteorological Research Institute
Osamu Uchino, Meteorological Research Institute
Isamu Yagai, Meteorological Research Institute
Koji Yamazaki, Meteorological Research Institute

International Sponsor: United Kingdom

Chemical, Dynamical, and Radiative Interactions through the Middle Atmosphere and Thermosphere

Principal Investigator—John A. Pyle

Dr. Pyle's Interdisciplinary Science Investigation will improve understanding of atmospheric dynamical, chemical, and radiative interactions—hence the ability to predict and detect long-term atmospheric trends in the Earth's climatic and chemical environment. Modeling and data analysis efforts will focus on the following middle atmosphere and thermosphere components:

- Circulation and internally generated variability of the atmosphere
- Interactions between chemical, dynamical, and radiative processes
- Horizontal and vertical coupling mechanisms.

The study will involve a two-pronged theoretical assault using EOS data and sophisticated numerical, dynamical, radiative, photochemical models of the troposphere, stratosphere, and mesosphere now being developed in the United Kingdom.

Dr. Pyle holds a D.Phil. in Atmospheric Physics from the University of Oxford. Since 1985, he has been a University Lecturer in Physical Chemistry at the University of Cambridge. Currently, he serves as Principal Investigator in the U.K. Universities Global Atmospheric Modeling Project supported by the National Environmental Research Centre. He is Chairman of the U.K. Stratospheric Ozone Review Group, and has served as a consultant to the European Space Agency on the future of middle atmospheric studies from space. In 1985, he was recipient of the Eurotrac Award of the Remote Sensing Society. ☆

Co-Investigators

Timothy J. Fuller-Rowel, University College–London
Lesley J. Gray, Rutherford Appleton Laboratory
Joanna D. Haigh, Imperial College of Science and Technology
Robert S. Harwood, University of Edinburgh
Brian Hoskins, University of Reading
R.L. Jones, University of Cambridge
Michael E. McIntyre, University of Cambridge
Roy J. Moffett, University of Sheffield
Shaun Quegan, University of Sheffield
David Rees, University College–London
Alan Rodger, British Antarctic Survey
Keith Shine, University of Reading

The Development and Use of a Four-Dimensional Atmospheric-Ocean-Land Data Assimilation System for EOS

Principal Investigator—Richard B. Rood

This Interdisciplinary Science Investigation will develop a research-quality, four-dimensional atmosphere-ocean-land data assimilation system for EOS. The project will research all aspects of four-dimensional data assimilation, including satellite retrievals, data quality control, error propagation, objective analysis, and all component models of the Earth system. The goals are to produce an assimilation analysis to ensure that the maximum information is gained from the observations and to set the foundation for future "Earth system models." Analyzing historical and new data sets available in the pre-launch phase of EOS will serve as the initial basis to confront Earth system problems, and the successes and failures of these diagnostic and interpretive studies will define the evolution of the data system. As such, a commitment will be made to continued reanalyses of these data sets. Data from satellites such as the Upper Atmosphere Research Satellite (UARS) will be used to assess the utility of new data types, such as wind and constituent data. Continual research into numerical techniques and associated Earth science process studies will ensure that the developed system meets the needs of EOS; furthermore, the involved data sets will be made available to the user community so that they can help define the system. Initial studies will concentrate on meteorology, with an emphasis on the hydrological cycle and seasonal and interannual variability. A strong emphasis will also be placed on global transport processes and atmospheric chemistry. From this core, the investigation will expand to cover more general aspects of Earth science as the proper expertise develops.

Richard B. Rood obtained a Ph.D. in Meteorology from Florida State University in 1982. Since then, he has been at NASA's Goddard Space Flight Center (GSFC). He has been involved in the development of atmospheric general circulation models, and three-dimensional chemistry and transport models. He has pioneered the use of winds and temperatures derived by data assimilation to study atmospheric transport processes. In 1992, he was appointed Head of the Data Assimilation Office at GSFC—the only center of data assimilation research that is not maintained within an operational weather forecasting center. The Data Assimilation Office produces research-quality data sets to study Earth system processes and global change. ☆

Co-Investigators

Robert M. Atlas, Goddard Space Flight Center
Wayman E. Baker, NOAA/National Meteorological Center
J. Ray Bates, Goddard Space Flight Center
Stephen Cohn, Goddard Space Flight Center
John Derber, NOAA/National Meteorological Center
Michael Fox-Rabinovitz, Goddard Space Flight Center
H. Mark Helfand, Goddard Space Flight Center
Arthur Hou, Goddard Space Flight Center
Donald R. Johnson, University of Wisconsin
A. James Miller, NOAA/National Meteorological Center
Eugenia Kalnay, NOAA/National Meteorological Center
Masao Kanamitsu, NOAA/National Meteorological Center
David J. Lamich, Goddard Space Flight Center
Ants Leetmaa, NOAA/National Meteorological Center
James Pfaendtner, Goddard Space Flight Center
Chester F. Ropelewski, NOAA/National Weather Service
Siegfried Schubert, Goddard Space Flight Center
Yogesh C. Sud, Goddard Space Flight Center
Joel Susskind, Goddard Space Flight Center
Larry Takacs, Goddard Space Flight Center

Polar Exchange at the Sea Surface (POLES): The Interaction of Oceans, Ice, and Atmosphere

Principal Investigator—Drew Rothrock

POLES is an investigation of the flux of heat, moisture, momentum, and gases across the surface of polar oceans, and of the role these fluxes play in global oceanic and atmospheric circulation. Even though fluxes are parameterized in a variety of ways in climate and general circulation models, these models uniformly predict that the largest response to changing atmospheric carbon dioxide occurs in polar regions. The purpose of this investigation is to assimilate a rich array of observations into polar ocean-atmosphere models, not only refining the treatment of surface exchange processes, but also quantifying the roles of horizontal transports, oceanic mixing, and deep convection. With better use of data, researchers can move beyond the present climatological descriptions—based on sparse observations—and document interannual variability. Polar oceanic stability is thought to be delicately balanced, allowing occasional episodes of deep convection which play a large role in driving the meridional circulation of the world ocean. The roles of precipitation, the sea ice melt/thaw cycle, and freshwater inputs from land in high-latitude deep convection need to be further clarified.

This investigation involves a blend of data assimilation, model development, and algorithm development for microwave, thermal, and visible sensors of surface properties and atmospheric vertical profiles. A major early focus is the improvement of visible and thermal algorithms, which presently are ill-suited to distinguish between clouds and a snow or ice surface. Another involves the interpretation of passive microwave signals in terms of important climatic quantities (e.g., snow cover) and the onset of surface melt and freeze-up. The long-term satellite passive microwave record is presently being assimilated into models of sea ice mass conservation and surface brine production.

Dr. Rothrock graduated summa cum laude from Princeton University in 1964, and earned his Ph.D. from the University of Cambridge in 1968. Since 1970, he has been affiliated with the University of Washington, where he is a Principal Research Scientist in the Applied Physics Laboratory, and an Associate Research Professor in the School of Oceanography. His research interests include sea ice dynamics and the remote sensing of polar geophysical processes with active and passive microwave, and thermal and visible satellite sensors. He has served as Associate Editor for the *Journal of Geophysical Research*, and is a member of the Alaska SAR Facility Science Team. ☆

Co-Investigators

Roger G. Barry, University of Colorado
Robert A. Brown, University of Washington
Frank Carsey, Jet Propulsion Laboratory
Jeffrey Key, University of Colorado
Seelye Martin, University of Washington
Michael Steele, University of Washington
Dale P. Winebrenner, University of Washington

Using Multi-Sensor Data to Model Factors Limiting Carbon Balance in Global Grasslands

Principal Investigator—David S. Schimel

Vegetation response to climate occurs through changing species composition and altered physiology. Dr. Schimel's team plans to couple a simple ecosystem model to spectral data from several EOS sensors to monitor changing patterns of physiology and ecosystem function in response to climate variability and directional change. The Interdisciplinary Science Investigation's primary objective will be to develop and evaluate a simulation model of ecosystem controls over the water, energy, and biogeochemical cycles, including trace gas emissions, within semi-arid ecosystems worldwide. Analytical techniques and mixing models will be developed to separate the remotely sensed canopy signal from background. Canopy parameters will be used as inputs to the simulation model. Multi-temporal remote sensing will then be used to drive simulations of seasonal and interannual response to climate.

David Schimel received his Ph.D. in 1982, and has been on the senior staff of the Natural Resources Ecology Laboratory since 1983. He holds a joint appointment with the Department of Forest Sciences. His research addresses basic questions in biogeochemical cycling and the development of techniques for extrapolating rates of processes to landscape and regional scales. Dr. Schimel is involved with the International Geosphere-Biosphere Program (IGBP) in the areas of trace gas exchange and global ecosystem modeling. ✩

Co-Investigators

Steven Archer, Texas A&M University
Brian Curtiss, University of Colorado
Alexander F.H. Goetz, University of Colorado
Timothy Kittel, Colorado State University
William Parton, Colorado State University
Carol A. Wessman, University of Colorado

Investigation of the Chemical and Dynamical Changes in the Stratosphere Up to and During the EOS Observing Period

Principal Investigator—Mark R. Schoeberl

This Interdisciplinary Science Investigation will characterize both anthropogenic and natural stratospheric changes. Primary output will be the generation of high-quality, long-term data sets for stratospheric ozone, temperature, and trace gases starting with the Nimbus-7 measurements, continuing with Upper Atmosphere Research Satellite (UARS) observations, and on through the EOS and UARS mission lifetimes using forecast/assimilation techniques. The assimilation analyses will provide dynamically and chemically balanced global representations of satellite and ground-based data. The assimilated data will significantly improve the evaluation of trace constituent budgets and meteorological diagnostics, and will help characterize dynamical/chemical/radiative interactions in the stratosphere.

Mark Schoeberl received an M.S. and Ph.D. from the University of Illinois. He has over 15 years of research experience in atmospheric dynamics, stratospheric physics, and numerical modeling. Dr. Schoeberl has been affiliated with NASA/Goddard Space Flight Center since 1983. Within his field of research, Dr. Schoeberl has chaired multiple conferences and committees, and served in an editorial capacity on numerous occasions. He is a recipient of the NASA Exceptional Scientific Achievement Medal, Naval Research Laboratory Publication Award, and NASA Technical and Group Achievement Awards. ☆

Co-Investigators

Anne R. Douglass, Goddard Space Flight Center
Marvin A. Geller, State University of New York–Stony Brook
Robert D. Hudson, University of Maryland–College Park
Charles H. Jackman, Goddard Space Flight Center
Leslie Robert Lait, Goddard Space Flight Center
Paul A. Newman, Goddard Space Flight Center
Richard B. Rood, Goddard Space Flight Center
Joan E. Rosenfield, Goddard Space Flight Center
Richard S. Stolarski, Goddard Space Flight Center
Anne M. Thompson, Goddard Space Flight Center

Biosphere-Atmosphere Interactions

Principal Investigator—Piers Sellers

Dr. Sellers' Interdisciplinary Science Investigation will examine the interaction between the land surface and the atmosphere, stressing the biospheric exchanges of energy, water, and carbon. The scope of research will be global, and will combine an extended time series of remote-sensing data with interpretive models and a realistic combined model of the terrestrial biosphere and the global atmosphere. Related work will focus on terrestrial ecosystem processes, particularly the use of models driven by satellite data. In carrying out this study, his team hopes to achieve some broader goals. In addition to improving the understanding of the critical components of the Earth system, the research will yield new and improved products of derived surface and atmospheric parameters, and will be directly useful in developing methodologies to extract maximum benefit from EOS observations.

Piers Sellers is an honors graduate of Edinburgh University, and received a Ph.D. from Leeds University in 1981. He has over 12 years of experience in the fields of natural and environmental resources, computer systems analysis, computer simulation, atmosphere/biosphere interactions, and remote sensing and meteorology. Dr. Sellers is based at NASA/Goddard Space Flight Center, Biospheric Sciences Branch. He has been extensively involved with the International Satellite Land Surface Climatology Project (ISLSCP), serving as Staff Scientist for the First ISLSCP Field Experiment (FIFE). ☆

Co-Investigators

Joe Berry, Carnegie Institution
Christopher Field, Carnegie Institution
Inez Fung, Goddard Institute for Space Studies
Christopher O. Justice, Goddard Space Flight Center
Pamela A. Matson, Ames Research Center
Harold Mooney, Stanford University
David A. Randall, Colorado State University
Compton J. Tucker, Goddard Space Flight Center
Susan Ustin, University of California–Davis
Peter Vitousek, Stanford University

Use of a Cryospheric System (CRYSYS) to Monitor Global Change in Canada

Principal Investigator—Réjean Simard

The polar regions prove particularly important in monitoring the effects of global change upon the environment. Changes in the atmosphere affect sea ice, land ice, permafrost, and snow cover, which in turn create fluctuations in the atmosphere, oceans, and freshwater. In order to effectively model the global climate, both long- and short-term records must be established and interpreted. Long-term information comes from the reconstruction of past climates using such sources as ice cores from glaciers and ice caps, and from borehole records in permafrost; short-term data are provided by climatological databases and remote-sensing sources. The compatibility of these data records and easy accessibility must be developed and sustained. This includes the verification of remote-sensing techniques, and determining the utility of these observations for use in environmental change studies.

The CRYSYS team will develop and validate the models necessary for using cryospheric information in the evaluation, understanding, and monitoring of the effects of global change. This will be accomplished by maintaining an extensive array of field sites in critical areas, and by developing algorithms for the extraction of geophysical variables for use in the initialization and validation of local, regional, and polar models.

Dr. Simard received a Ph.D. in Geophysics from the University of Lausanne in 1980. He has been a research scientist at the Canada Center for Remote Sensing since that time; since 1987, he has also been an Adjunct Professor at Sherbrooke University. His experience includes remote sensing, geophysics, and natural resources studies. He has been a Principal Investigator on several projects, including an evaluation of the Systeme pour l'Observation de la Terre-1 (SPOT-1) satellite system for production of digital terrain models and geoscience-related applications. ☆

Co-Investigators

Francis Bowkett, Canadian Climate Centre
Melinda Brugman, National Hydrology Research Institute
Josef Cihlar, Canada Centre for Remote Sensing
Demetris Delikaraoglou, Canada Centre for Surveying
John Falkingham, Canadian Ice Centre
Terry Fisher, Canada Centre for Remote Sensing
Hugh French, University of Ottawa
Barry Goodison, Canadian Climate Centre
Hardie Granberg, University of Sherbrooke
Allen Judge, Geological Survey of Canada
Roy Koerner, Geological Survey of Canada
Robert Leconte, Canada Centre for Remote Sensing
Ellsworth LeDrew, University of Waterloo
Marlon Lewis, Dalhousie University
Michael Manore, Canada Centre for Remote Sensing
Barry Maxwell, Canadian Climate Centre
Marie-Catherine Mouchot, Canada Centre for Remote Sensing
Lawrence Mysak, McGill University
Simon Ommaney, National Hydrology Research Institute
Terry Prowse, National Hydrology Research Institute

International Sponsor: United Kingdom

Middle and High Latitudes Oceanic Variability Study

Principal Investigator—Meric A. Srokosz

This Interdisciplinary Science Investigation will build on ongoing and planned field work to examine the spatial and temporal variability of the eastern North Atlantic and Southern Oceans. Determining the long-term and large-scale means and trends in the structure of the oceans receives most emphasis within the oceanic community at large; however, Dr. Srokosz recognizes the importance of understanding variability as well. This investigation will make significant use of the microwave, visible, and infrared EOS sensors to investigate the variability of the atmospheric forcing of the oceans, the consequent effect on oceanic response, and the impact on the oceans' biological productivity. These data will be combined in a synergistic manner and assimilated into an ocean model; the result will be statistical descriptions of the temporal and spatial variability of the atmosphere-ocean biology system, and their interrelationships on space scales ranging from 1 to 1,000 km and time scales of days to years.

Meric Srokosz has 12 years of experience in the fields of applied mathematics, remote sensing of oceans, and radar altimetry. He holds both undergraduate and doctoral degrees in Mathematics from Bristol University. Currently, he serves on the Natural Environment Research Council (NERC) Remote-Sensing Applications Development Unit of the British National Space Centre, where he is responsible for coordination of United Kingdom activities in remote sensing of the oceans, and for the development of applications and research on remote sensing of the oceans. Dr. Srokosz is a Principal Investigator for the European Remote-Sensing Satellite-1 (ERS-1) mission, and Co-Investigator on the Ocean Topography Experiment (TOPEX)/Poseidon and Shuttle Imaging Radar-C (SIR-C) missions. ☆

Co-Investigators

Peter G. Challenor, James Rennell Centre for Ocean Circulation
Mike Fasham, James Rennell Centre for Ocean Circulation
Trevor Guymer, James Rennell Centre for Ocean Circulation
John Marshall, Massachusetts Institute of Technology
Ian Robinson, University of Southampton
Peter K. Taylor, James Rennell Centre for Ocean Circulation

Earth System Dynamics: The Determination and Interpretation of the Global Angular Momentum Budget Using EOS

Principal Investigator—Byron D. Tapley

This Interdisciplinary Science Investigation will develop system models to efficiently use the multi-sensor information obtained from EOS—in combination with other satellite and in situ data—to investigate the interactions of the atmosphere, oceans, and solid Earth, and the exchange of energy and angular momentum between these components of the Earth's dynamic system. Specific objectives include the use of EOS precursor mission data to understand the contribution of air, water, and atmospheric motion to Earth rotation variations and related angular momentum exchange; establishing a terrestrial reference system for monitoring tectonic and global sea level change over multiple decades; and understanding how mountain torques and surface friction couple angular momentum variations of the oceans, atmosphere, and solid Earth.

Dr. Tapley earned a Ph.D. in Engineering Mechanics at the University of Texas–Austin, and has over 30 years of experience in the use of satellites for Earth observations. He has served on the National Research Council (NRC) Space Studies Board (SSB), the SSB Committee on Earth Studies, and the NRC Earth Studies Board Geodesy Committees. He began teaching at his alma mater in 1958. Since 1984, he has held the Clare Cockrell Williams Centennial Chair in the Department of Aerospace Engineering and Engineering Mechanics, and he serves as Director of the Center for Space Research. He is also the Director of the Texas Space Grant Consortium. His research interests focus on the application of nonlinear parameter estimation methods to determine crustal motion, Earth rotation, the Earth's geopotential, and ocean circulation. He has served on numerous NASA advisory committees, including the EOS Science Steering Committee. He has served as Chairman of the Geodesy Section for the American Geophysical Union (AGU). He received the NASA Exceptional Scientific Achievement Medal in 1983, and the American Institute of Aeronautics and Astronautics (AIAA) Mechanics and Control of Flight Award in 1989. He is a member of the National Academy of Engineering, and a Fellow of AGU, AIAA, and AAS. ☆

Co-Investigators

Richard Eanes, University of Texas–Austin
John Lundberg, University of Texas–Austin
Rui M. Ponte, Atmospheric and Environmental Research, Inc.
Richard D. Rosen, Atmospheric and Environmental Research, Inc.
David A. Salstein, Atmospheric and Environmental Research, Inc.
Bob E. Schutz, University of Texas–Austin
C.K. Shum, University of Texas–Austin
Clark R. Wilson, University of Texas–Austin

An Interdisciplinary Investigation of Clouds and Earth's Radiant Energy System: Analysis

Principal Investigator—Bruce A. Wielicki

Dr. Wielicki's Interdisciplinary Science Investigation will provide EOS with a consistent database of accurately known fields of radiation and cloud properties. Radiative data will be provided as fluxes at the top of the Earth's atmosphere, at the Earth's surface, and as flux divergences within the atmosphere. Cloud properties will be provided as measured areal coverage, cloud altitude, shortwave and longwave optical depths, cloud particle size, and condensed water density. The large systematic diurnal variations of radiation and clouds will be resolved by analyzing data from three spacecraft: The EOS-AM and -PM polar platforms, and the Japanese platform employing a 55° inclined orbit. The combination of these data with global climate model studies will allow the determination of the interaction of clouds with the Earth's climate—a critical issue for understanding global change. Pre-launch studies of this investigation's radiative transfer models and data analysis algorithms will use existing satellite data [i.e., Advanced Very High-Resolution Radiometer (AVHRR), High-Resolution Infrared Sounder (HIRS), and Earth Radiation Budget Experiment (ERBE)] along with field measurements of clouds and radiation collected during the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE).

Dr. Wielicki was awarded a Ph.D. in Physical Oceanography from the Scripps Institution of Oceanography in 1980. His research has focused primarily on cloud properties, cloud retrieval, and the Earth radiation budget. Following a 3-year assignment with the National Center for Atmospheric Research, Dr. Wielicki joined NASA/Langley Research Center as a research scientist in 1980. While there, he served as Principal Investigator on the Landsat Thematic Mapper (TM) science team. Ongoing projects include work as Co-Investigator on ERBE and Principal Investigator for FIRE. ☆

Co-Investigators

Bruce R. Barkstrom, Langley Research Center
Maurice L. Blackmon, NOAA/Environmental Research Laboratory
Robert D. Cess, State University of New York
Thomas P. Charlock, Langley Research Center
James A. Coakley, Oregon State University
Dominique Crommelynck, Royal Meteorological Institute
Wayne L. Darnell, Langley Research Center
Richard N. Green, Langley Research Center
Edwin F. Harrison, Langley Research Center
Robert S. Kandel, Ecole Polytechnique
Michael D. King, Goddard Space Flight Center
Robert B. Lee III, Langley Research Center
Alvin J. Miller, NOAA/National Meteorological Center
Patrick Minnis, Langley Research Center
V. Ramanathan, Scripps Institution of Oceanography
David Randall, Colorado State University
G. Louis Smith, Langley Research Center
Larry L. Stowe, NOAA/National Environmental Satellite, Data, and Information Service
John T. Suttles, NASA Headquarters
Ronald M. Welch, South Dakota School of Mines and Technology

EOS Points-of-Contact

PRECEDING PAGE BLANK NOT FILMED

EOS INSTRUMENTS

ACRIM Principal Investigator
Richard C. Willson
Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 171-400
Pasadena, California 91109
Phone: 818/354-3529
E-Mail(1): JPL::RCWILLSON::SPAN
E-Mail(2): ACRIM/NASAMAIL
Telex: 675429
FAX: 818/354-4707

AIRS/AMSU/MHS Team Leader
Moustafa T. Chahine
Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 180-904
Pasadena, California 91109
Phone: 818/354-6057
E-Mail(1): MCHAHINE/NASAMAIL
E-Mail(2): M.CHAHINE/OMNET
Telex: 275165
FAX: 818/393-4218

ASTER Team Leader (Japan)
Hiroji Tsu
Geological Survey of Japan
1-1-3 Higashi Ibaraki-ken
Tsukuba-shi 305
Japan
Phone: 81-298543610
E-Mail: tsu@gsj.go.jp
FAX: 81-298543571

ASTER Team Leader (U.S.)
Anne Kahle
Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 183-501
Pasadena, California 91109
Phone: 818/354-7265
E-Mail: [sec.326/j.p.l.]
Telex: 7401843
FAX: 818/354-0966

CERES Principal Investigator
Bruce R. Barkstrom
NASA/Langley Research Center
Mail Stop 423
Hampton, Virginia 23681-0001
Phone: 804/864-5676
E-Mail(1): brb@ceres.larc.nasa.gov
E-Mail(2): BRBARKSTROM/NASAMAIL
Telex: 8823405 NASA HAMP
FAX: 804/864-7996

DORIS/SSALT/TMR Team Leader
Lee-Lueng Fu (Interim U.S.)
Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 300-323
Pasadena, California 91109
Phone: 818/354-8167
E-Mail: L.FU/OMNET
Telex: 675429
FAX: 818/393-6720

EOSP Principal Investigator
Larry D. Travis
NASA/Goddard Institute for Space Studies
2880 Broadway
New York, New York 10025
Phone: 212/678-5599
E-Mail: LTRAVIS/NASAMAIL
FAX: 212/678-5622

GLAS Team Leader
Bob E. Schutz
University of Texas–Austin
Center for Space Research
Building WRW, Room 402C
Austin, Texas 78712-1085
Phone: 512/471-4267
E-Mail(1): BSCHUTZ/GSFCMAIL
E-Mail(2): schutz@utcsr.ae.utexas.edu
Telex: 704265 CSRUTX UD
FAX: 512/471-3570

HIRDLS Co-Principal Investigator
John Barnett
Oxford University
Atmospheric, Oceanic, and Planetary Sciences
Clarendon Laboratory
Oxford, OX1 3PU
UK
Phone: 44-865272909
E-Mail(1): barnett@isams.atm.ox.ac.uk
E-Mail(2): JBARNETT/GSFCMAIL
FAX: 44-865272923

HIRDLS Co-Principal Investigator
John C. Gille
National Center for Atmospheric Research
Atmospheric Chemistry Division
P.O. Box 3000
Boulder, Colorado 80307-3000
Phone: 303/497-1402
E-Mail(1): gille@ncar.ucar.edu
E-Mail(2): JGILLE/GSFCMAIL
Telex: 989764
FAX: 303/497-1492

LIS Principal Investigator
Hugh J. Christian
Marshall Space Flight Center
Code ES43
Huntsville, Alabama 35812
Phone: 205/544-1649
E-Mail: HCHRISTIAN/NASAMAIL
FAX: 205/544-5760

MIMR Team Leader (U.S.)
Pending negotiation with ESA
Roy W. Spencer
NASA/Marshall Space Flight Center
Code ES43
Huntsville, Alabama 35812
Phone: 205/544-1686
E-Mail: RSPENCER/NASAMAIL
FAX: 205/544-5760

MISR Principal Investigator
David J. Diner
Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 169-237
Pasadena, California 91109
Phone: 818/354-6319
E-Mail: DJDINER/NASAMAIL
Telex: 675429
FAX: 818/393-4619

MLS Principal Investigator
Joe W. Waters
Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 183-701
Pasadena, California 91109
Phone: 818/354-3025
E-Mail: [jwaters/j.p.l.]
Telex: 675429
FAX: 818/393-5065

MODIS Team Leader
Vincent V. Salomonson
NASA/Goddard Space Flight Center
Code 900
Greenbelt, Maryland 20771
Phone: 301/286-8601
E-Mail(1): VSALOMONSON/GSFCMAIL
E-Mail(2): V.SALOMONSON/OMNET
Telex: 248496/197640
FAX: 301/286-3884

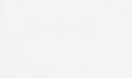
MOPITT Principal Investigator
James R. Drummond
University of Toronto
Department of Physics
60 St. George Street
Toronto, Ontario M5S 1A7
Canada
Phone: 416/978-4723
E-Mail:
jim@atmosp.physics.utoronto.ca
FAX: 416/978-8905

NSCAT II Principal Investigator
Michael H. Freilich
Oregon State University
College of Oceanography and Atmospheric Sciences
Oceanography Administration Bldg. 104
Corvallis, Oregon 97331-5503
Phone: 503/737-2748
E-Mail(1): mhf@oce.orst.edu
E-Mail(2): M.FREILICH/OMNET
FAX: 503/737-2064

SAGE III Principal Investigator
M. Patrick McCormick
NASA/Langley Research Center
Mail Stop 475
Hampton, Virginia 23681-0001
Phone: 804/864-2669
E-Mail: MPMCCORMICK/NASAMAIL
Telex: 823405 NASA HAMP
FAX: 804/864-2671

SOLSTICE II Principal Investigator
Gary J. Rottman
National Center for Atmospheric Research
High Altitude Observatory
P.O. Box 3000
Boulder, Colorado 80307-3000
Phone: 303/497-1515
E-Mail(1): rottman@virgo.hao.ucar.edu
E-Mail(2): VIRGO::ROTTMAN
FAX: 303/497-1589

TES Principal Investigator
Reinhard Beer
Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 183-301
Pasadena, California 91109
Phone: 818/354-4748
E-Mail: RBEER/GSFCMAIL
Telex: 675429
FAX: 818/393-4445



EOS INTERDISCIPLINARY SCIENCE INVESTIGATIONS

Mark R. Abbott
Principal Investigator
Oregon State University
College of Oceanography and Atmospheric Sciences
Oceanography Administration Bldg. 104
Corvallis, Oregon 97331-5503
Phone: 503/737-4045
E-Mail(1): mabbott@oce.orst.edu
E-Mail(2): M.ABBOTT/OMNET
FAX: 503/737-2064

Eric J. Barron
Principal Investigator
Pennsylvania State University
Earth System Science Center
248 Deike Building
University Park, Pennsylvania 16802
Phone: 814/865-1619
E-Mail(1): eric@essc.psu.edu
E-Mail(2): E.BARRON/OMNET
Telex: 842510
FAX: 814/865-3191

Getulio T. Batista
Principal Investigator
Instituto Nacional de Pesquisas Espaciais
C.P. 515 Av. Dos Astronautas
1758 Sao Jose dos Campos
Sao Paulo 12201
Brazil
Phone: 55-123418977
E-Mail: getulio@ltid.inpe.br
Telex: 123-3530
FAX: 55-123218743

Peter G. Brewer
Principal Investigator
Monterey Bay Aquarium Research Institute
160 Central Avenue
Pacific Grove, California 93950
Phone: 408/647-3706
E-Mail(1): P.BREWER/OMNET
E-Mail(2): brpe@mbari.org
FAX: 408/649-8587

Josef Cihlar
Principal Investigator
Canada Centre for Remote Sensing
588 Booth Street
4th Floor
Ottawa, Ontario K1A 0Y7
Canada
Phone: 613/952-0500
E-Mail(1): cihlar@ccrs.emr.ca
E-Mail(2): J.CIHLAR/OMNET
Telex: 053-3777
FAX: 613/947-1385

Robert E. Dickinson
Principal Investigator
University of Arizona
Institute of Atmospheric Physics
PAS Building, No. 81
Tucson, Arizona 85721
Phone: 602/621-2810
E-Mail:
robted@air.atmo.arizona.edu
FAX: 602/621-6833

Jeff Dozier
Principal Investigator
Center for Remote Sensing and Environmental Optics
University of California–Santa Barbara
Santa Barbara, California 93106
Phone: 805/893-2309
E-Mail(1): dozier@crseo.ucsb.edu
E-Mail(2): J.DOZIER/OMNET
Telex: 89675
FAX: 805/893-2578

William L. Grose
Principal Investigator
NASA/Langley Research Center
Mail Stop 401B
Hampton, Virginia 23681-0001
Phone: 804/864-5820
E-Mail: WLGROSE/NASAMAIL
Telex: 823405
FAX: 804/864-6326

James E. Hansen
Principal Investigator
NASA/Goddard Institute for Space Studies
2880 Broadway
New York, New York 10025
Phone: 212/678-5619
E-Mail: JHANSEN/GSFCMAIL
FAX: 212/678-5622

Graham P. Harris
Principal Investigator
Commonwealth Scientific and Industrial Research Organization
Office of Space Science and Applications
G.P.O. Box 3023
Canberra, ACT 2601
Australia
Phone: 61-62790800
E-Mail(1): G.HARRIS/OMNET
E-Mail(2): harris@cbr.cossa.csiro.au
Telex: AA61371
FAX: 61-62790812

Dennis L. Hartmann
Principal Investigator
University of Washington
Department of Atmospheric Science
Code AK-40
Seattle, Washington 98195
Phone: 206/543-7460
E-Mail(1):
dennis@atmos.washington.edu
E-Mail(2): D.HARTMANN/OMNET
Telex: 328000
FAX: 206/543-0308

Bryan L. Isacks
Principal Investigator
Cornell University
Snee Hall
Ithaca, New York 14853-1504
Phone: 607/255-2307
E-Mail(1): isacks@geology.cornell.edu
E-Mail(2): BISACKS/GSFCMAIL
Telex: WUI 6713054
FAX: 607/254-4780

Yann H. Kerr
Principal Investigator
Laboratoire d'Etudes et de Recherches en Teledetection Spatiale
18 Avenue Edouard Belin
Toulouse, Cedex 31055
France
Phone: 33-61274472
E-Mail(1): Y.KERR/OMNET
E-Mail(2): YKERR/GSFCMAIL
Telex: 531081 Ler France
FAX: 33-61281410

William K.M. Lau
Principal Investigator
NASA/Goddard Space Flight Center
Code 913
Greenbelt, Maryland 20771
Phone: 301/286-7208
E-Mail(1): lau@climate.gsfc.nasa.gov
E-Mail(2): W.LAU/OMNET
Telex: 248496/197640
FAX: 301/286-4804

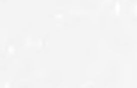
John F. LeMarshall
Principal Investigator
Bureau of Meteorology Research Centre
Satellite Section
G.P.O. Box 1289
Melbourne, Victoria 3001
Australia
Phone: 61-36694420
E-Mail: BMRC.AUSTRALIA/OMNET
Telex: AA 30434
FAX: 61-36694660

W. Timothy Liu
Principal Investigator
Jet Propulsion Laboratory
4800 Oak Grove Drive
Mail Stop 300-323
Pasadena, California 91109
Phone: 818/354-2394
E-Mail: T.LIU/OMNET
Telex: 675429
FAX: 818/393-6720

Berrien Moore III
Principal Investigator
University of New Hampshire
Institute for the Study of Earth, Oceans, and Space
Science and Engineering Research Building
Durham, New Hampshire 03824
Phone: 603/862-1766
E-Mail: B.MOORE.UNH/OMNET
Telex: 7407346
FAX: 603/862-1915

Peter J. Mouginis-Mark
Principal Investigator
University of Hawaii
Hawaii Institute of Geophysics
Planetary Geosciences Division
2525 Correa Road
Honolulu, Hawaii 96822
Phone: 808/956-3147
E-Mail: P.MOUGINIS.MARK/OMNET
Telex: UNIHAW
FAX: 808/956-6322

Masato Murakami
Principal Investigator
Typhoon Research Institute
Meteorological Research Institute
1-1 Nagamine Ibaraki-ken
Tsukuba-shi 305
Japan
Phone: 81-298517111
E-Mail: TYPHOON.MRI/OMNET
FAX: 81-298511449



John Adrian Pyle
Principal Investigator
Cambridge University
Department of Chemistry
Lensfield Road, Cambridge CB2 1EW
UK
Phone: 44-22361188
E-Mail(1): u_hjm@vaxc.nerc-bas.ac.uk
E-Mail(2): JPYLE/GSFCMAIL
Telex: 81240 CAMSPLG
FAX: 44-223467390

Jeffrey E. Richey
Lead U.S. Co-Investigator
University of Washington
School of Oceanography
Code WB-10
Seattle, Washington 98195
Phone: 206/543-7339
E-Mail(1): J.RICHEY/OMNET
E-Mail(2): jrichey@u.washington.edu
Telex: 4740096 UW UI
FAX: 206/543-6073

Richard B. Rood
Principal Investigator
NASA/Goddard Space Flight Center
Code 916
Greenbelt, Maryland 20771
Phone: 301/286-8203
E-Mail(1): rood@sgccp.gsfc.nasa.gov
E-Mail(2): RROOD/GSFCMAIL
Telex: 248496/197640
FAX: 301/286-3460

Drew Rothrock
Principal Investigator
University of Washington
Applied Physics Laboratory
Polar Science Center
1013 NE 40th Street
Mail Stop HN-10
Seattle, Washington 98195
Phone: 206/685-2262
E-Mail(1): D.ROTHROCK/OMNET
E-Mail(2):
rothrock@apl.washington.edu
Telex: 740-1427
FAX: 206/543-3521

David S. Schimel
Principal Investigator
Colorado State University
Natural Resource Ecology Laboratory
140 Grassland Laboratory
Fort Collins, Colorado 80523
Phone: 303/491-1974
E-Mail(1): schimel@niwot.scd.ucar.edu
E-Mail(2): D.SCHIMEL/OMNET
FAX: 303/991-1965

Mark R. Schoeberl
Principal Investigator
NASA/Goddard Space Flight Center
Code 916
Greenbelt, Maryland 20771
Phone: 301/286-5819
E-Mail(1): schom@odin1.gsfc.nasa.gov
E-Mail(2): MSCHOEBERL/GSFCMAIL
Telex: 248496/197640
FAX: 301/286-3460

Piers Sellers
Principal Investigator
NASA/Goddard Space Flight Center
Code 923
Greenbelt, Maryland 20771
Phone: 301/286-7282
E-Mail: exops@ltp.gsfc.nasa.gov
FAX: 301/286-9200

Réjean Simard
Principal Investigator
Canada Centre for Remote Sensing
1547 Merivale Road
Ottawa, Ontario K1A 0Y7
Canada
Phone: 613/952-2700
Telex: 053-3117
FAX: 613/952-7353

Soroosh Sorooshian
Lead U.S. Co-Investigator
University of Arizona
Department of Hydrology and Water Resources
Old Geology Building 11, Room 122
Tucson, Arizona 85721
Phone: 602/621-1661
E-Mail(1): soroosh@hwr.arizona.edu
E-Mail(2): soroosh@arizvms.bitnet
Telex: 9109521143
FAX: 602/621-1422

Meric A. Srokosz
Principal Investigator
James Rennell Centre for Ocean Circulation
Chilworth Research Centre
Gamma House
Chilworth, Southampton S01 7NS
UK
Phone: 44-703766184
E-Mail(1): MSROKOSZ/GSFCMAIL
E-Mail(2): M.SROKOSZ/OMNET
E-Mail(3): mas@uk.ac.nso.ub
FAX: 44-703767507

Byron D. Tapley
Principal Investigator
University of Texas–Austin
Center for Space Research
Building WRW, Room 402D
Austin, Texas 78712
Phone: 512/471-5573
E-Mail: B.TAPLEY/OMNET
Telex: 704265 CSRUTX UD
FAX: 512/471-3570

Bruce A. Wielicki
Principal Investigator
NASA/Langley Research Center
Mail Stop 420
Hampton, Virginia 23681-0001
Phone: 804/864-5683
E-Mail(1): wielick@asdsun.larc.nasa.gov
E-Mail(2): BAWIELICKI/NASAMAIL
Telex: 823405
FAX: 804/864-7996

EOS PROGRAM/PROJECT

EOS Program Scientist
Ghassem Asrar
NASA Headquarters
Mail Code SE
300 E Street, SW
Washington, DC 20024
Phone: 202/358-2559
E-Mail(1): G.ASRAR/OMNET
E-Mail(2): gasrar@sedsparc.ossa.hq.nasa.gov
FAX: 202/358-2770

EOS Project Scientist
Michael King
NASA/Goddard Space Flight Center
Code 900
Greenbelt, Maryland 20771
Phone: 301/286-8228
E-Mail: king@climate.gsfc.nasa.gov
Telex: 197640 NASACOM GBLT
FAX: 301/286-3884

EOS Acronyms

PRECEDING PAGE BLANK NOT FILMED

[illegible] 140 [illegible]

Acronyms

AAOE	Airborne Antarctic Ozone Experiment
AATSR	Advanced Along-Track Scanning Radiometer
ACR	Active Cavity Radiometer
ACRIM	Active Cavity Radiometer Irradiance Monitor
ADC	Affiliated Data Center
ADEOS	Advanced Earth Observing System
AES	Atmospheric Environment Service
AGU	American Geophysical Union
AIAA	American Institute of Aeronautics and Astronautics
AIRS	Atmospheric Infrared Sounder
ALEXIS	Array of Low Energy X-Ray Imaging Sensors
ALT	Altimeter
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
AMTS	Advanced Moisture and Temperature Sounder
AO	Announcement of Opportunity
APT	Automatic Picture Transmission
ARA	Atmospheric Radiation Analysis
ARGOS	Argos Data Collection and Position Location System
ARMSAT	Atmospheric Radiation Measurement Satellite
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced Scatterometer
ASF	Alaska SAR Facility
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATES	Alcatel Espace Systems
ATLAS	Atmospheric Laboratory for Applications and Science
ATMOS	Atmospheric Trace Molecules Observed by Spectroscopy
AVHRR	Advanced Very High-Resolution Radiometer
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
AVNIR	Advanced Visible and Near-Infrared Radiometer
BRDF	Bidirectional Reflectance Distribution Function
CCD	Charged Coupled Device
CCRS	Canada Centre for Remote Sensing
CDDIS	Crustal Dynamics Data Information System
CDMS	Cryospheric Data Management System
CEES	Committee on Earth and Environmental Sciences
CEOS	Committee on Earth Observations Satellites
CERES	Clouds and Earth's Radiant Energy System
CFC	Chlorofluorocarbon
CIESIN	Consortium for International Earth Science Information Network
CLAES	Cryogenic Limb Array Etalon Spectrometer
CNES	Centre National d'Etudes Spatiales
CNRS	Centre National de la Recherche Scientifique
COARE	Coupled Ocean-Atmosphere Response Experiment
CODMAC	Committee on Data Management, Archiving, and Computing
COSPAR	Congress for Space Research
CPP	Cloud Photopolarimeter
CRYSYS	Cryospheric System
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organization
CU	University of Colorado
CZCS	Coastal Zone Color Scanner
DAAC	Distributed Active Archive Center
DADS	Data Archive and Distribution System
DAS	Direct Access System
DB	Direct Broadcast
DCS	Data Collection System
DDL	Direct Downlink
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DOS	Department of State
DP	Direct Playback
DRSS	Data Relay Satellite System
DSB	Direct Sounding Broadcast
EC	European Community
ECS	EOSDIS Core System
EDC	EROS Data Center
EDOS	EOS Data and Operations System
EER	External Engineering Review
ELV	Expendable Launch Vehicle
ENSO	El Niño Southern Oscillation
ENVISAT	Environmental Satellite
EOC	EOS Operations Center
EO-ICWG	Earth Observations International Coordination Working Group
EOS	Earth Observing System
EOS-AERO	EOS Aerosol Mission
EOS-ALT	EOS Altimetry Mission
EOS-AM	EOS Morning Crossing (Ascending) Mission
EOSAT	Earth Observation Satellite Company
EOS-CHEM	EOS Chemistry Mission
EOSDIS	EOS Data and Information System
EOSP	Earth Observing Scanning Polarimeter
EOS-PM	EOS Afternoon Crossing (Descending) Mission

EP	Earth Probe
EPA	Environmental Protection Agency
EPOP	European Polar-Orbiting Platform
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Radiation Budget Satellite
EROS	Earth Resources Observation System
ERS	European Remote-Sensing Satellite
ERTS-1	Earth Resources Technology Satellite-1
ESA	European Space Agency
ESDIS	Earth Science Data and Information System
ESSC	Earth System Sciences Committee
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FIFE	First ISLSCP Field Experiment
FIRE	First ISCCP Regional Experiment
FORTE	Fast On-Orbit Recording of Transient Events
FOV	Field-of-View
FST	Field Support Terminal
FY	Fiscal Year
GAC	Global Area Coverage
GCC	Global Change Category
GCDIS	Global Change Data and Information System
GEO	Geostationary Earth Observation
Geosat	Navy Geodetic Satellite
GEWEX	Global Energy and Water Cycle Experiment
GGI	GPS Geoscience Instrument
GISS	Goddard Institute for Space Studies
GLAS	Geoscience Laser Altimeter System
GLI	Global Imager
GLIS	Global Land Information System
GLL	Galileo
GLRS	Geoscience Laser Ranging System
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GOMI	Global Ozone Monitoring Instrument
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOMR	Global Ozone Monitoring Radiometer
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
HI	Human Interactions
HIRDLS	High-Resolution Dynamics Limb Sounder
HIRIS	High-Resolution Imaging Spectrometer
HIRS	High-Resolution Infrared Sounder
HIS	High-Resolution Interferometer Sounder
HRPT	High-Resolution Picture Transmission
IASI	Infrared Atmospheric Sounding Interferometer
IAU	International Astronomical Union
ICC	Instrument Control Center
ICF	Instrument Control Facility
ICSU	International Council of Scientific Unions
IEEE	Institute for Electronics and Electrical Engineering
IELV	Intermediate Expendable Launch Vehicle
IEOS	International Earth Observing System
IFOV	Instantaneous Field-of-View
IFREMER	Institut Francais de Recherche pour l'Exploration de la Mer
IGBP	International Geosphere-Biosphere Program
ILAS	Improved Limb Atmospheric Spectrometer
IMG	Interferometric Monitor for Greenhouse Gases
IMS	Information Management System
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IPOC	International Partner Operations Center
IR	Infrared
IRTS	Infrared Temperature Sounder
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climatology Project
IST	Instrument Support Terminal
ITIR	Intermediate Thermal Infrared Radiometer
IWG	Investigator Working Group
IWGDMGC	Interagency Working Group on Data Management for Global Change
JEOS	Japanese Earth Observing System
JERS	Japan's Earth Resources Satellite
JGOFS	Joint Global Ocean Flux Study
JMA	Japan Meteorological Agency
JPL	Jet Propulsion Laboratory
JPOP	Japanese Polar-Orbiting Platform
LAC	Local Area Coverage
LAGEOS	Laser Geodynamics Satellite
Landsat	Land Remote-Sensing Satellite
LaRC	Langley Research Center
LERTS	Laboratoire d'Etudes et de Recherches en Teledetection Spatiale
Lidar	Light Detection and Ranging
LIDQA	Landsat Image Data Quality and Analysis
LIMS	Limb Infrared Monitor of the Stratosphere
LIS	Lightning Imaging Sensor
LITE	Lidar In-Space Technology Experiment

LMD	Laboratoire de Meteorologie Dynamique
LR	Laser Retroreflector
LRPT	Low-Resolution Picture Transmission
MCP	Meteorological Communications Package
MELV	Medium Expendable Launch Vehicle
MERIS	Medium-Resolution Imaging Spectrometer
MESSR	Multispectrum Electronic Self-Scanning Radiometer
METOP	Meteorological Operational Satellite
MHS	Microwave Humidity Sounder
MIMR	Multifrequency Imaging Microwave Radiometer
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MISR	Multi-Angle Imaging SpectroRadiometer
MIT	Massachusetts Institute of Technology
MITI	Ministry of International Trade and Industry
MLS	Microwave Limb Sounder
MODIS	Moderate-Resolution Imaging Spectroradiometer
MODIS-N	Moderate-Resolution Imaging Spectrometer—Nadir
MOP	Meteosat Operational Programme
MOPITT	Measurements of Pollution in the Troposphere
MOS	Marine Observation Satellite
MOU	Memorandum of Understanding
MSFC	Marshall Space Flight Center
MSR	Microwave Scanning Radiometer
MSS	Multispectral Scanner
MSU	Microwave Sounding Unit
MTPE	Mission to Planet Earth
MTS	Microwave Temperature Sounder
MU	Microwave Unit
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency
NBIS	Northern Biosphere Information System
NCAR	National Center for Atmospheric Research
NCDS	NASA Climate Data System
NERC	National Environmental Research Centre
NESDIS	National Environmental Satellite, Data, and Information Service
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NODS	NASA Ocean Data System
NRA	NASA Research Announcement
NRC	National Research Council
NREN	National Research and Education Network
NSC	National Security Council
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSN	NASA Space Network
NSpC	National Space Council
NSPD	National Space Policy Directive
NWP	Numerical Weather Prediction
OCTS	Ocean Color and Temperature Scanner
ODB	Orbit Determination Beacon
ODC	Other Data Center
OLS	Optical Line Scanner
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratory
OSC	Orbital Sciences Corporation
OSTP	Office of Science and Technology Policy
PGS	Product Generation System
PI	Principal Investigator
PL	Public Law
PLDS	Pilot Land Data System
PMR	Pressure-Modulated Radiometer
POEM	Polar-Orbit Earth Observation Mission
POES	Polar-Orbiting Operational Environmental Satellite
POLDER	Polarization and Directionality of Earth's Reflectances
POLES	Polar Exchange at the Sea Surface
PPR	Photopolarimeter Radiometer
PR	Precipitation Radar
PRAREE	Precise Range and Range Rate Equipment—Extended
PU	Processing Unit
QC	Quality Control
RA	Radar Altimeter
Radarsat	Radar Satellite
RF	Radio Frequency
RIS	Retroreflector In Space
RPM	Revolutions Per Minute
S&R	Search and Rescue
SAFIRE	Spectroscopy of the Atmosphere using Far Infrared Emission
SAGE	Stratospheric Aerosol and Gas Experiment
SAMS	Stratospheric and Mesospheric Sounder
SAR	Synthetic Aperture Radar
SBUV	Solar Backscatter Ultraviolet
SCARAB	Scanner for the Radiation Budget
SCF	Science Computing Facility
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
Seasat	Sea Satellite
SeaWiFS	Sea-Viewing Wide Field Sensor
SEDAC	Socio-Economic Data and Applications Center
SELV	Small Expendable Launch Vehicle

SEM	Space Environment Monitor
S-GCOS	Space-Based Global Change Observation System
SI	Solar Influences
SIR-C	Shuttle Imaging Radar-C
SLR	Satellite Laser Ranging
SMC	System Management Center
SMMR	Scanning Multispectral Microwave Radiometer
SNR	Signal-to-Noise Ratio
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPOT	Systeme pour l'Observation de la Terre
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSM/I	Special Sensor Microwave/Imager
SRL	Shuttle Research Laboratory
SSALT	Solid-State Altimeter
SSEC	Space Science and Engineering Center
SSB	Space Studies Board
SSU	Stratospheric Sounding Unit
STA	Science and Technology Agency
STIKSCAT	Stick Scatterometer
SWG	Science Working Group
SWIR	Short Wavelength Infrared
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
TES	Tropospheric Emission Spectrometer
TGDDIS	Trace Gas Dynamics Data Information System
TIR	Thermal Infrared
TIROS	Television Infrared Observing Satellite
TM	Thematic Mapper
TMI	TRMM Microwave Imager
TMR	TOPEX Microwave Radiometer
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
UAF	University of Alaska–Fairbanks
UARP	Upper Atmosphere Research Program
UARS	Upper Atmosphere Research Satellite
UAV	Unmanned Aerospace Vehicle
UHF	Ultra High Frequency
U.K.	United Kingdom
U.S.	United States
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
USO	Ultra-Stable Oscillator
UV	Ultraviolet
VIRS	Visible Infrared Scanner
VIRSR	Visible Infrared Scanning Radiometer
VIS	Visible
VHF	Very High Frequency
VNIR	Visible and Near -Infrared
VTIR	Visible and Thermal Infrared Radiometer
WCRP	World Climate Research Program
WFF	Wallops Flight Facility
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WSMC	Western Space and Missile Center
X-SAR	X-Band Synthetic Aperture Radar

END

DATE

FILMED

MAY 20 1993